J Sci Educ Technol
DOI 10.1007/s10956-015-9548-6

Technologies and Reformed-Based Science Instruction: The Examination of a Professional Development Model Focused on Supporting Science Teaching and Learning with Technologies

Todd Campbell · Max L. Longhurst · Shiang-Kwei Wang · Hui-Yin Hsu · Dan C. Coster

Abstract While access to computers, other technologies, and cyber-enabled resources that could be leveraged for enhancing student learning in science is increasing, generally it has been found that teachers use technology more for administrative purposes or to support traditional instruction. This use of technology, especially to support traditional instruction, sits in opposition to most recent standards documents in science education that call for student involvement in evidence-based sense-making activities. Many see technology as a potentially powerful resource that is reshaping society and has the potential to do the same in science classrooms. To consider the promise of technology in science classrooms, this research investigated the impact of a professional development project focused on enhancing teacher and student learning by using information and communication technologies (ICTs) for engaging students in reformed-based instruction. More specifically, these findings revealed positive teacher outcomes with respect to reformed-based and technology-supported instruction and increased ICT and new literacies skills. When considering students, the findings revealed positive outcomes with respect to ICT and new literacies skills and student achievement in science.

Keywords Professional development · Reformed-based instruction · Technology integration

Introduction

Technology should be an important modern aspect of science teaching and learning, especially when consideration is given to ways in which technology is shaping or re-shaping lives and society. In our previous research (Campbell et al. 2014), we noted how this transformation is occurring in students' lives as social networking, online gaming, iPods, and mobile phones are found as fixtures of youth culture (Ito et al. 2008) or as science fields are emerging (Hey et al. 2009) and science practices are being transformed with technology (Sabelli 2006). Beyond this, educational researchers and learning scientists have recognized the promise of technology for supporting design and research in teaching and learning. This can be seen as Squire (2006) explains how educational games can be used as design platforms for scaffolding learning or supporting identity development or how Clark and Sampson (2008) examine methodologies for studying argumentation in online environments, as just two examples. Based on the ubiquitous nature of technology in society and the potential of technology in educational settings, it is clear that consideration of technology in science teaching and learning is warranted. But, when technology has been used in science classrooms, only a moderate amount is known about the impact of technology. This can be seen as researchers like Anastopoulou et al. (2012) and Soong and Mercer (2011),

T. Campbell (✉)
University of Connecticut, Storrs, CT, USA
e-mail: todd.campbell@uconn.edu

M. L. Longhurst · D. C. Coster
Utah State University, Logan, UT, USA
e-mail: max.longhurst@usu.edu

D. C. Coster
e-mail: dan.coster@usu.edu

S.-K. Wang · H.-Y. Hsu
New York Institute of Technology, New York, NY, USA
e-mail: shiang-kwei.wang@nyit.edu

H.-Y. Hsu
e-mail: huiyinh@gmail.com

as just two examples, demonstrate the generally positive impacts of novel interventions in science classrooms. However, for the most part, technology research in science education is only somewhat informed by themes such as technologies supportive of enhanced content knowledge learning (e.g., Lee and Thomas 2011; Park et al. 2009) and enhancing students' experiences engaging in science (e.g., Wu 2010; Ebenezer et al. 2011).

When considering teaching with technology more specifically, the lack of teacher confidence with technology (Lussier et al. 2007; Mumtaz 2000; Zhao and Cziko 2001) and the lack of support in the form of professional development (Baylor and Ritchie 2002; Lim and Chai 2008) have been identified as factors that inhibit technology transformations in science teaching and learning. But, technology-enhanced tools like scientific visualizations are being identified that show promise in supporting teachers' efforts to adopt reformed-based science instructional practices (Varma et al. 2008). Additionally, promising evidence can be found to suggest that when teachers are supported with ongoing professional development focused on the use of new technologies aligned with reformed-based science instruction, positive teacher and student outcomes emerge (Bell et al. 2013; Lussier et al. 2007; Quintana et al. 2004). And, researchers like Linn et al. (2003) have demonstrated how flexibly adaptive design environments like their web-based inquiry science environment (WISE) can meet the needs of diverse groups of teachers in supporting reformed-based science instruction. Still, investigations into the effectiveness of specific professional development models in supporting teachers' technology integration and reformed-based instructional practices are needed.

This present study attends to this need by investigating the impact of a professional development model focused on enhancing teacher and student learning by using information and communication technologies (ICTs) for engaging students in reformed-based science instruction. More specifically, to investigate the effectiveness of the professional development model, we addressed two research questions:

1. What is the impact of 1 year of professional development on:
   (a) reformed-based and technology-integrated instruction?
   (b) teacher learning?
   (c) teacher and student new literacies skills and ICT capabilities?
2. What is the impact of typical instruction versus professional development model supported instruction on student achievement?

Research on Reformed-Based Technology-Supported Science Teacher Professional Development

More broadly, PD literature extols the importance of focusing on subject matter, opportunities for collaborative interactions among teachers, and seamlessly integrating PD and classroom experiences to allow participants to examine the basis of what is being learned or created in the context that it will be employed (Lemke 2001; Birman et al. 2000; Carlone and Webb 2006; Garet et al. 2001; Hawley and Valli 1999; Richardson 2003; Stein et al. 1999). When considering science teacher PD specifically, a consensus model of best practices can be found, but as Roth et al. (2011) explain, this is not well grounded in research evidence that demonstrates teacher learning, teacher practice, and student learning. Higgins and Spitulnik (2008) further illuminate this concern:

> Professional development research must continue to pursue evidence of the elusive connections between teachers' participation in professional development, their decisions about and enactment of inquiry in science instruction, and the impact on student achievement (p. 520).

This is not to say that examples of PD research that investigate teacher and student outcomes measures cannot be found (e.g., Akerson and Hanuscin 2007; Johnson et al. 2006); it is only to document the need for additional research, especially research that examines the impact (i.e., in terms of teacher and student learning outcomes) of types or models of PD with specific features to build on the body of science teacher PD knowledge.

When technology is considered in the context of reformed-based science teaching and learning and science teacher PD, a dimension of complexity that warrants attention is added (Singer et al. 2000). In fact, when considering technology, researchers (e.g., Crippen 2012; Koehler and Mishra 2005; Niess 2005; Pamuk 2012) have proposed that technology represents another realm of science teacher knowledge. As an extension of Shulman's (1986) pedagogical content knowledge (PCK), this new version of teacher knowledge is referred to as technological pedagogical content knowledge (TPACK) (Koehler and Mishra 2005). In science teaching specifically, we have shared examples (e.g., Campbell and Abd-Hamid 2013; Campbell and Neilson 2009) of what TPACK might look like within reformed-based visions of science teaching. As an example, we (Campbell and Neilson 2009) described how a science teacher selected and used technologies like probeware as tools alongside science practices and in coordination with disciplinary core ideas to develop evidence-based explanations. And, because researchers like Bull and Bell (2009) have suggested that "if TPACK is an important prerequisite to effective integration of technology in education, a method for measuring it seems essential" (p. 2); we have also developed instrumentation support of this, which is being used in this current research (i.e., a classroom observations protocol) (Campbell and Abd-Hamid 2013).

However, while efforts have been made to support TPACK for reformed-based science instruction, Bell et al. (2013), Campbell et al. (2013), and Hsu and Wang (2013) note how, to date, for the most part teachers have been found using technologies for more administrative purposes or to support traditional instruction. Examples of this type of technology use might be teachers converting lecture notes to PowerPoint presentations to support sharing information with students, using videos for presenting information in place of lectures, or using software programs as homework to track students scores as they solve more traditional problems in science (e.g., completing stoichiometry problems for a chemistry class).

Still, further details of the complexity of reformed-based technology-supported science teacher PD can be seen as several comprehensive literature reviews have been completed to work at synthesizing the research base in this area (e.g., Gerard et al. 2011; Higgins and Spitulnik 2008; Lawless and Pellegrino 2007). Among the most salient findings from these studies, is articulated by Lawless and Pellegrino (2007) as they described how their review provided only limited insight into the types of pedagogical changes teachers made when integrating technology into instruction or the impacts technology-focused professional development had on teacher development. In fact, the paucity of information about teacher pedagogical changes or teachers' development as a result of PD commonly surfaced in the reviews completed (Gerard et al. 2011; Higgins and Spitulnik 2008). Therefore, while literature can be found that attests to the benefits of technology in supporting reformed-based science teaching and learning (e.g., Higgins and Spitulnik 2008; Varma et al. 2008; Williams et al. 2004), still the need exists for additional investigations that can speak to how teachers' pedagogy and development change as a result of engagement in reformed-based technology-supported science teacher PD.

The present study is seen as an important contribution to PD literature more generally as it focuses on the "elusive connections between teachers' participation in professional development, their decisions about and enactment of inquiry in science instruction, and the impact on student achievement" (Higgins and Spitulnik 2008, p. 520). Additionally, the present study is also seen as an important contribution to the literature as it focuses on how teachers' pedagogy and development change as a result of engagement in technology-enhanced science teacher PD.

Background

Setting

This study focused on sixth- through eighth-grade science teachers and students from two geographically separated states: one in the eastern and one in the western part of the USA. In the state located in the eastern part of the USA, teachers from the sample population of participants came from 10 schools in two boroughs in New York City. New York City is one of the US cities with the most diverse student population. Among all the public school students, 14.3 % are Caucasian, 29.9 % are African-American, 39.3 % are Hispanic, and 14.9 % are Asian. 15.4 % of the students are classified as English Language Learners (ELL) (Lowenstein 2011). In the state located in the western part of the USA, teachers from the sample population of participants came from two school districts, in Utah. Similar to most western states, the state where the study was completed has a majority white population, with a Hispanic population with the highest minority prevalence (US Census Bureau 2010).

The study followed participants from fall 2011 to spring 2012. The reformed-based technology-supported science teacher professional development project was an intensive program, engaging participants in 80 h of professional development during the summer, followed by another 16 h of monthly meetings during the academic year, and 24 h of professional development during the winter for a total of 120 h yearly. The professional development project emphasized technology-supported reformed-based instructional practices. Technology-supported reformed-based instruction refers to the instructional strategies that focus on using technologies, such as ICTs, in ways that support new literacies development and the engagement in science literacy practices with inquiry as a central mode of teaching science.

Methods

Professional Development

This research took place over a 1-year period with data collection at the beginning and end of 1 year. As articulated above, the goal of the project is to enhance teacher and student learning by fostering instructional strategies that focus on using technologies, such as ICTs, in ways that support new literacies development and the engagement in science literacy practices with inquiry as a central mode of teaching science. To accomplish this goal, the project uses educative curriculum (Davis and Krajcik 2005) to ground the PD experience for participants, where educative curriculum is understood as curriculum that is intended to promote both teacher and student learning. During the year of PD, in total, two (7–9 days) curriculum modules were developed by the PD leadership team and used as PD learning anchors for teacher participants and their students. Each module was developed in alignment with a modified version of Slater et al. (2008) backward faded scaffolding inquiry, whereby the learner experiences increasing levels of independence through three iterations of cohesive investigations. To offer a better sense of the educative curriculum used in the project and the subsequent teacher and student technology-supported reformed-based experiences, a vignette from an exemplar module is highlighted in Table 1.

The PD model as depicted in Fig. 1 is conceived with a theory of action proposing that as teacher participants engage as learners in the project developed curriculum and subsequently enact the curriculum in their classrooms, their content, and pedagogical knowledge will be enhanced so that teacher learning, teaching practice, and student learning are improved, both within and beyond the project curriculum modules anchoring the PD.

Beyond the structure of the PD outlined in Fig. 1, an outline of the PD experiences of teachers during the summer workshop, fall monthly meetings, winter workshop, and spring monthly meetings is shared in Table 2.

Research Design

This study consisted of a comparison of teachers' before and after 1 year of PD instructional practices and learning, a comparison of teachers' and students' before and after 1 year of PD new literacies skills and ICT capabilities, and a comparison of student achievement of students taught by a teacher who participated in the professional development (intervention) versus students in a delayed-treatment group from comparable schools whose teachers did not participate in PD (comparison). Therefore, with respect to teacher instructional practices and content learning and teacher and student new literacies skills, the design is best described as a one-group pretest/posttest design. With respect to student achievement, the study is best described as a posttest-only, quasi-experimental, control-group design. Teacher instructional practices were assessed with the Reformed Teaching Observation Protocol (Piburn et al. 2000) and Technology Use in Science Instruction (Campbell and Abd-Hamid 2013) observation protocol in March or April prior to PD and again in March or April at the end of the year of PD. Teacher learning was assessed with a post-workshop questionnaire after the summer PD workshop. Teacher and student new literacies skills and ICT capabilities were assessed with the new literacies scenarios (NLS) and ICT capabilities instruments, developed by the Hsu et al. (2013), in April or May prior to PD and again in April or May at the end of the year of PD. Finally, student achievement was assessed for students of teachers in the western USA by the Utah criterion-referenced test (CRT) in science at the end of the year of their teachers participating in PD (Note: Student achievement data from students of teacher participants in the eastern part of the USA were not made available to the PD providers; therefore, only student achievement data from students of teacher participants in the western USA were used). More about each instrument employed is shared in Table 3.

Sample and Sample Selection

As depicted in Table 4, there were 27 (intervention) teacher participants in the project in the year of PD investigated in this research, while there were 30 (control) teacher

Table 1 Educative curriculum module exemplar vignette

The following is a vignette that describes students' experiences engaging in the exemplar module titled Human Impact on Water Quality (Hsu and Wang 2013). Teachers experience this module as learners as part of the summer PD, before taking it into their classrooms and enacting it with students in the fall
When trying to determine the role humans have played in changing the environment, students use web search engines to look for news articles about this topic in their neighborhoods to figure out what factors and how these factors might affect local water quality (e.g., increasing pH levels). After determining real-life problems through researching news article, the teacher guides the students in considering how credible cyber databases (e.g., USGS) might be used to determine whether evidence can be found associating water quality with factors they are interested in investigating. As part of this process, students use spreadsheets to log and organize data (such as the locations of the data collected and time of data collected) and create charts to analyze the relationships among various factors. Additionally, students can use mapping tools to mark the locations of the data collected for further comparisons and analyses. They might use GeoPhotos found in Google Earth to examine geographical environments or pictures of the body of water they are investigating to ensure they have considered other factors that may contribute to changing pH levels in water. Students then use Google Docs to organize their research results and collaboratively present their work using charts, tables, pictures, and maps. The teacher can ask students to share their work through social networking sites (e.g., Edmodo) and also have them critique each other's projects
This vignette demonstrates the seamless integration of new literacy (i.e., using ICTs to identify, locate, evaluate, synthesize, and communicate information) to support sense making in reformed-based science instruction. The following ICTs were adopted in this example: web search engines, cyber databases, spreadsheet, charts, GeoPhotos, Google Earth, Google Docs, and Edmodo

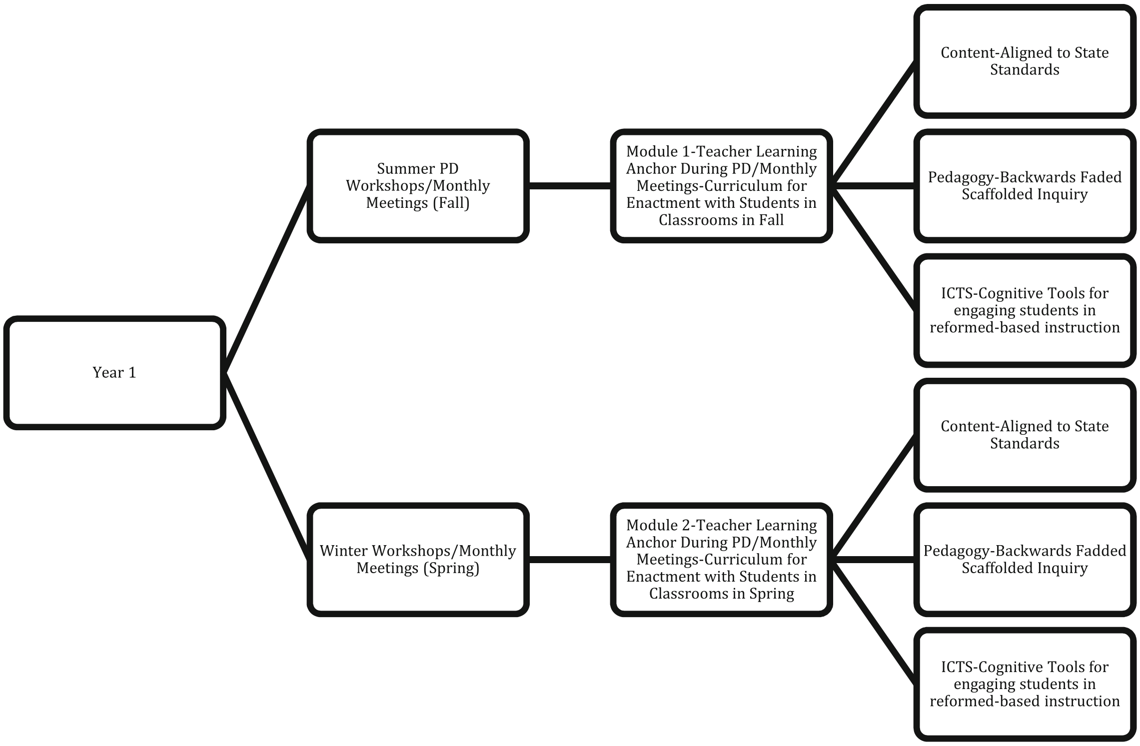

Fig. 1 Hybridized science content-pedagogy-curriculum material-driven orientation PD

participants. From these 27 (intervention) teacher participants, observations were completed for 18 participants prior to PD and at the end of the year of PD, while observations were completed for all 30 participants in the delayed-treatment control group (Note: observations were not completed for nine intervention group participants prior to the PD for various reasons including participants being recruited after the academic year when observations would have been possible. This was not an issue the second year of the project when the control group was recruited; therefore, all 30 delayed-treatment control teachers were observed prior to PD. All 27 of the intervention teacher participants completed the teacher learning survey. Additionally, 24 intervention teacher participants completed a new literacies and ICT capabilities survey prior to PD and at the end of 1 year of PD. Additionally, 1,050 students of teacher participants completed the new literacies and ICT capabilities surveys at the beginning and at the end of the 2012–2013 academic year. Finally, the CRT was administered to students of participants in the western part of the USA to 1,143 students of 14 (intervention) teacher participants and 1,153 students of 11 (control) teacher participants in the delayed-treatment group.

Since random sampling in this project was not possible because of the difficulties of recruiting participants, especially those that would serve in delayed-treatment cohorts either 1 year or 2 years after the initial recruitment, the sample selection method for assigning teachers to cohorts and consequently control and intervention groups in this research is best described as convenience sampling. This is recognized as a necessary limitation of this research, but one that was mitigated to some extent by comparing classroom observations of instructional practices prior to teacher participant's participation in the project to demonstrate the similarities among the intervention and control participant groups (see Table 5).

As can be seen in Table 5, when classroom observations of teachers prior to engaging in PD were compared using the Reformed Teaching Observation Protocol (RTOP) and Technology Use in Science Instruction (TUSI), instruments described in detail in the following section, no significant differences were found [i.e., $t(46) = 0.02$, $p = 0.9870$ and $t(46) = -1.82$, $p = 0.0747$, respectively]. This offers some initial evidence of the similarities between all groups of teachers participating or those readying to participate in the future (i.e., the delayed-treatment group) and helps to somewhat mitigate concerns for sampling bias at the teacher level.

Data Analysis

Two different data analyses strategies were used. First, to investigate the impact of the PD on teacher reformed-based and technology-integrated instruction, teacher learning,

Table 2 Structure of summer workshop, fall monthly meetings, winter workshop, and spring monthly meetings

Workshop session	Description
Summer workshop (9 days)	*Day 1–5*
	Teachers engage in Module 1 educative curriculum (9 days × 45 min class periods) with "learner hats" on and PD providers as instructors
	In between class period sessions, teachers with "teacher hat" on discuss facilitation of each class period and makes notes in teacher constructed instructional guide to supplement instructional notes provided in educative curriculum
	Day 6–9
	Prepare materials for enactment in classroom in the fall. This involves creating cloud-based materials for class sections, developing strategies for enactment in schools taking into account technology, policy, and scheduling constraints and affordances of their schools
	Teachers consider ways in which technologies (e.g., ICTs) can be used to support new literacy and reformed-based science instruction beyond the educative curriculum they will enact in the Fall
Fall monthly meetings (4 × 2 h after school)	*Month 1 meeting*
	Revisiting principles of reformed-based instruction and new literacy. Additional Time spent preparing to enact Module 1 in the classroom
	Month 2 meeting
	Reflecting on enactment of Module 1/sharing student artifacts from Module 1
	Month 3 meeting
	Sharing emergent teacher created tools that emerged during enactment/completion and discussion of fidelity logs detailing specifics of enactment
	Month 4 meeting
	Revisiting Module 1 to discuss possible modifications based on enactment
Winter workshop	*Day 1–2 meeting*
	Teachers engage in Module 2 educative curriculum (9 days × 45 min class periods) with "learner hats" on and PD providers as instructors
	In between class period sessions, teachers with "teacher hat" on discuss facilitation of each class period and makes notes in teacher constructed instructional guide to supplement instructional notes provided in educative curriculum
	Day 3
	Prepare materials for enactment in classroom in the spring. This involves creating cloud-based materials for class sections, developing strategies for enactment in schools taking into account technology, policy, and scheduling constraints and affordances of their schools
	Teachers consider ways in which technologies (e.g., ICTs) can be used to support new literacy and reformed-based science instruction beyond the educative curriculum they will enact in the spring
Spring monthly meetings (4 × 2 h after school)	*Month 1 meeting*
	Revisiting principles of reformed-based instruction and new literacy. Additional Time spent preparing to enact Module 2 in the classroom
	Month 2 meeting
	Reflecting on enactment of Module 2/sharing student artifacts from Module 2
	Month 3 meeting
	Sharing emergent teacher created tools that emerged during enactment/completion and discussion of fidelity logs detailing specifics of enactment
	Month 4 meeting
	Revisiting Module 2 to discuss possible modifications based on enactment

and teacher and student new literacies skills and ICT capabilities, descriptive statistics were determined for the pre- and post-measures for each instrument used (i.e., RTOP, TUSI, workshop questionnaires, NLS, ICT capabilities) before matched-pairs *t* tests were conducted to compare participants mean pretest to posttest change scores (posttest minus pretest values) on each total instrument score and the subscale/construct scores for each instrument. An exception to this analysis was the analysis of teacher learning where paired-samples *t* tests were only conducted at the construct level. In addition to an assessment of the statistical significance of the mean posttest minus pretest score (*p* value), effect sizes were calculated as the difference given by the posttest mean minus the pretest mean divided by an estimate of the pooled standard deviation of the change score (i.e., Cohen's effect size measure, *d*). The

Table 3 Research instruments employed

Instruments	Description
Reformed-based and technology-integrated instruction: RTOP (Piburn et al. 2000) and TUSI (Campbell and Abd-Hamid 2013)	The RTOP was selected because it measures "reformed" teaching as described by national science standards documents (American Association for the Advancement of Science 1989; NRC 1996). The RTOP consists of 25 indicators that are Likert-scaled ranging from very descriptive (4) to never occurred (0). The items are grouped into three subsets: *Design and Implementation, Content,* and *Classroom Culture*. The TUSI was selected because it measures the extent to which technology integration in science classrooms is aligned with reformed, science inquiry-focused instruction (Campbell and Abd-Hamid 2013). The TUSI consists of 26 items that are Likert-scaled ranging from very descriptive (4) to never occurred (0). The items are divided into five constructs. Five raters, external to the project, completed the classroom observations. Inter-rater reliability was established with all raters at .80 or greater
Teacher learning: retrospective post-summer workshop questionnaire	Teacher learning was measured using a post-summer workshop questionnaire that asked teacher participants about their: (Construct 1) understanding of science content addressed in the workshop (3 items); (Construct 2) preparedness to engage in practices consistent with the nature of science (10 items). Multiple items for each teacher learning outcome were grouped together into composite scores for each of these constructs to help combat the potential unreliability of individual questionnaire items. A "retrospective pre-approach" is useful with surveys when respondents are likely to change their perceptions of initial knowledge/preparedness as they learn more about a topic (Goedhart and Hoogstraten 1992; Howard et al. 1979; Klatt and Taylor-Powell 2005; Lamb 2005; Pratt et al. 2000). Additionally, acceptable to excellent reliability for each composite/construct was found using Cronbach's coefficient alpha (i.e., ranging between 0.58 and 0.93 for the two constructs)
Teacher and student new literacies skills and ICT capabilities: new literacies scenarios (NLS) instrument (Hsu et al. 2013) and ICT literacy survey (Markauskaite 2007)	New literacies skills were measured with the new literacies scenarios (NLS) instrument (Hsu et al. 2013). This is a 31-item instrument consisting of three scenarios situated in middle school teaching and learning with each scenario followed by several items listing the procedure and new literacies skills needed throughout the scenario. The instrument uses a Likert scale ranging from (1) "I am not familiar with how to do it," to (5) "I am very familiar with how to do it and can teach others to do it" To measure teachers' ICT capabilities, an adaptation of the ICT literacy survey developed by Markauskaite (2007) was used since it measures technical and cognitive capabilities. The survey consists of 35 items and was originally intended to measure pre-service teachers' confidence in the following five components of ICTs and cognitive skills: problem solving, communication and metacognition, basic ICT capabilities, analysis and production with ICTs, and information- and internet-related skills
Student achievement: Utah criterion-referenced tests (CRT)	The Utah criterion-referenced test (CRT) was used to assess student achievement. The Utah Science CRTs were selected to measure student achievement because they are reported to be "high quality, valid, aligned, reliable assessments to measure student understanding of core content-specified concepts to appropriately inform instructional and accountability decisions" (USOE 2007)

following Cohen effect sizes were used: 0.1–0.3 are small to medium, while those from 0.3 to 0.5 are medium to large (Cohen 1988).

Second, to investigate the impact of the PD on student achievement, descriptive statistics were determined for the students of participant teachers (intervention) and students of non-participating delayed-treatment teachers (control) measures for the CRT before independent-sample t tests were conducted to compare intervention and control group mean student scores on the total CRT score and each subscale/construct scores for CRT. Additionally, scores were disaggregated and t tests were conducted to examine intervention and control group student scores for the following different student demographics: white/non-white

Table 4 Sample

	Teacher participants	Classroom observations	Teacher learning surveys	Teacher ICT/NLS surveys	Students ICT/NLS surveys	Teachers' students CRT scores
Intervention	27	18	27	24	1,050	1,143
Control	30	30	–	–	–	1,153

Table 5 Pre-intervention group versus pre-delayed-treatment group classroom observation comparisons

	Cohort	*n* size	Mean	SD	*t*	*p* Value
RTOP scale						
1	Intervention	18	1.53	1.09	−0.33	0.7414
	Control	30	1.63	0.96		
2	Intervention	18	2.32	0.79	−0.34	0.7346
	Control	30	2.41	0.85		
3	Intervention	18	1.37	1.06	0.43	0.6669
	Control	30	1.22	1.18		
4	Intervention	18	1.57	1.09	0.27	0.7856
	Control	30	1.49	0.91		
5	Intervention	18	2.07	1.07	−0.07	0.9464
	Control	30	2.09	0.94		
Total	Intervention	18	1.77	0.96	0.02	0.9870
	Control	30	1.77	0.88		
TUSI scale						
1	Intervention	18	0.33	0.52	−1.89	0.0648
	Control	30	0.94	1.29		
2	Intervention	18	0.31	0.54	−1.73	0.0897
	Control	30	0.79	1.10		
3	Intervention	18	0.54	0.92	−1.68	0.1000
	Control	30	1.08	1.16		
4	Intervention	18	0.32	0.58	−1.87	0.0679
	Control	30	0.91	1.24		
5	Intervention	18	0.19	0.53	−1.46	0.1508
	Control	30	0.61	1.13		
Total	Intervention	18	0.35	0.59	−1.82	0.0747
	Control	30	0.88	1.14		

RTOP scales: 1 = lesson design/implementation; 2 = propositional knowledge; 3 = procedural knowledge; 4 = communication and interaction; 5 = student/teacher relations. TUSI scales: 1 = context; 2 = worthwhile; 3 = unique features; 4 = more accessible; 5 = technology/science distinction

and socioeconomic status. (Note: *p* values are unadjusted). Because of the multiple constructs for each instrument and the use of the same groups of participants, a Bonferroni approach is indicated for assessment of the statistical significance of the differences of means. Thus, for study instruments with 5–6 scales comparisons, *p* values less than (about) 0.01 rather than the traditional 0.05 α level imply a significant difference, while *p* values below 0.003 might be interpreted as highly statistical significant.)

Findings

The findings are organized by the research questions.

Research Question 1 What is the impact of 1 year of professional development on:

(a) reformed-based and technology-integrated instruction?
(b) teacher learning?
(c) teacher and student new literacies skills and ICT capabilities?

Reformed-Based and Technology-Integrated Instruction

Table 6 reveals the descriptive statistics for the classroom observations completed using the RTOP and TUSI both prior to PD and at the end of the year of PD. When considering instruction, based on independent-sample *t* tests completed, time engaged in PD was found to be an influential factor affecting both reformed-based and technology-enhanced instruction, $t(18) = 2.94$, $p < 0.009$; $t(18) = 4.51$, $p < 0.001$, respectively. Additionally, significant increases (i.e., *p* values less than (about) 0.01) in reformed-based and technology-enhanced instruction were found for 3/5 of the constructs for RTOP and all of the constructs of TUSI each construct (see Table 6).

In addition to comparisons made with the RTOP and TUSI ratings prior to PD and at the end of 1 year of PD for teachers in the intervention group, RTOP and TUSI ratings from after 1 year of PD from the intervention group were compared to the RTOP and TUSI ratings for the delayed-treatment group prior to engaging in PD (see Table 7).

As can be seen in Table 7, when considering differences between instruction of intervention teachers after 1 year of PD compared to delayed-treatment teachers prior to PD, based on independent *t* tests completed, again time engaged in PD was found to be an influential factor positively affecting both reformed-based and technology-enhanced instruction, $t(46) = 3.33$, $p < 0.002$; $t(46) = 3.24$, $p < 0.002$, respectively. Additionally, significant increases [i.e., *p* values less

Table 6 Before and after PD RTOP ($n = 18$) and TUSI results: before PD and after PD and after PD − before PD

	Before PD		After PD		Difference: after PD − before PD			
	Mean	SD	Mean	SD	Mean	SD	t	p value
Scale								
1	1.53	1.09	2.62	1.32	1.09	1.39	3.33	0.0040**
2	2.32	0.79	3.08	0.60	0.76	1.03	3.10	0.0064**
3	1.37	1.06	2.21	1.40	0.84	1.64	2.18	0.0432*
4	1.57	1.09	2.48	1.03	0.91	1.57	2.47	0.0245*
5	2.07	1.07	3.07	1.03	1.00	1.43	2.97	0.0087**
Overall	1.77	0.96	2.69	1.00	0.92	1.33	2.94	0.0092**
TUSI ($n = 18$)								
1	0.33	0.52	1.97	1.63	1.63	1.67	4.16	0.0007***
2	0.31	0.54	2.13	1.58	1.80	1.69	4.39	0.0005***
3	0.54	0.92	2.29	1.59	1.75	1.79	4.16	0.0007***
4	0.32	0.58	2.00	1.68	1.68	1.79	3.97	0.0010***
5	0.19	0.53	1.79	1.58	1.60	1.51	4.49	0.0003***
Overall	0.35	0.59	2.15	1.53	1.78	1.63	4.51	0.0004***

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

than (about) 0.01] in reformed-based and technology-enhanced instruction were found for all of the constructs for RTOP and TUSI, except for Construct 1, context, where increases were found, but were not significant at the more stringent 0.01 α-level.

Teacher Learning

Table 8 reveals the descriptive statistics for the pre-/post-composites for teacher learning. With respect to teacher learning, based on the two-tailed paired-samples t tests completed to test participant teachers' retrospective perceptions pre- to post, time engaged in the PD summer workshop was found to be an influential factor affecting both (Construct 1) understanding of science content addressed in the workshop and (Construct 2) preparedness to engage in practices consistent with the nature of science. This can be seen as significant differences were found for both constructs. Additionally, the 20-point or greater differences on Constructs 1 and 2 are equivalent to large effect sizes of 1.16 and 1.67 standard deviations.

Teacher and Student New Literacies Skills and ICT Capabilities

Table 9 reveals the descriptive statistics for the pre-/post-composites for teacher ICT capabilities (i.e., ability to use ICTs) and new literacies scenarios (NLS) (i.e., new literacies skills), while Table 10 reveals these for students. Pre- and post-intervention self-reporting surveys focused on ICT capabilities and NLS examined whether differences could be found between pre- and post-intervention. When

Table 7 Intervention group after 1 year of PD versus delayed-treatment group prior to PD classroom observation comparisons

	Cohort	n size	Mean	SD	t	p Value
RTOP scale						
1	Intervention	18	2.62	1.32	3.00	0.0044**
	Control	30	1.63	0.96		
2	Intervention	18	3.08	0.60	2.93	0.0053**
	Control	30	2.41	0.85		
3	Intervention	18	2.21	1.40	2.62	0.0118**
	Control	30	1.22	1.18		
4	Intervention	18	2.48	1.03	3.48	0.0011**
	Control	30	1.49	0.91		
5	Intervention	18	3.07	1.03	3.36	0.0016**
	Control	30	2.09	0.94		
Total	Intervention	18	2.69	1.00	3.33	0.0017**
	Control	30	1.77	0.88		
TUSI scale						
1	Intervention	18	1.97	1.63	2.41	0.0198*
	Control	30	0.94	1.29		
2	Intervention	18	2.13	1.58	3.41	0.0014**
	Control	30	0.79	1.10		
3	Intervention	18	2.29	1.59	3.03	0.0040**
	Control	30	1.08	1.16		
4	Intervention	18	2.00	1.68	2.58	0.0131**
	Control	30	0.91	1.24		
5	Intervention	18	1.79	1.58	3.02	0.0041**
	Control	30	0.61	1.13		
Total	Intervention	18	2.15	1.53	3.24	0.0023**
	Control	30	0.88	1.14		

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$. RTOP scales

Table 8 Teacher learning results: post-summer workshop questionnaire ($n = 27$)

Construct	Prior to workshop		After workshop		Effect size (in SD)
	Mean	SD	Mean	SD	
1	73.25	16.67	93.42*	10.34	1.16
2	69.11	16.99	93.48*	10.55	1.67

* $p \leq 0.05$. Construct scales: 1 = science content; 2 = nature of science

considering ICT capabilities and NLS, based on independent t tests completed, significant increases in overall ICT capabilities and NLS from pre- to post-intervention surveys were found for both teachers and students, teacher: $t(24) = 4.45$, $p < 0.001$; $t(24) = 8.71$, $p < 0.001$ and student: $t(1{,}050) = 9.28$, $p < 0.001$; $t(1{,}050) = 20.76$, $p < 0.001$, respectively. Additionally, significant increases were found for all constructs for teachers and students, except when considering Scale 1 and 2 for teachers of ICT Capabilities (i.e., problem solving, communication, and metacognition).

Research Question 2 What is the impact of typical instruction versus professional development model supported instruction on student achievement?

Table 11 reveals the descriptive statistics for the students of participant teachers (intervention) and students of non-participating delayed-treatment teachers (control) measures for the CRT before independent-sample t tests were conducted to compare intervention and control group student scores on the total CRT score and each subscale/construct scores for CRT. Additionally, Table 12 reveals disaggregated scores and t tests completed to examine intervention and control group student scores for the following different student demographics: white intervention versus white control, non-white intervention versus non-white control. And finally, Table 13 reveals disaggregated scores and t tests completed to examine intervention and control group student scores for the high socioeconomic intervention group versus high socioeconomic control group and low socioeconomic intervention group versus low socioeconomic control group. As can be seen in Table 11, students of participant teachers (intervention) performed significantly higher than students of non-participating delayed-treatment teachers (control) overall on the state standardized examination $t(1{,}153) = 2.80$, $p < 0.005$. Table 11 also reveals differences among intervention and control student achievement at the standard level of modules that served as learning anchors for PD and classroom enactment. More specifically, the analysis revealed that students of teacher participants classrooms performed statistically better for both standards targeted (i.e., Standard II and Standard IV).

Beyond investigating overall student achievement, as can be seen in Table 12, when white and non-white students were separated and analyzed, almost all significant differences between the intervention and control students

Table 9 Teacher ICT capabilities ($n = 24$) and new literacies scenarios results: before PD and after PD and after PD − before PD

	Before PD		After PD		Difference: after PD − before PD				Effect size
	Mean	SD	Mean	SD	Mean	SD	t	p Value	
Scale									
1	4.28	0.48	4.47	0.36	0.19	0.45	2.02	0.0548	0.41
2	4.41	0.67	4.50	0.40	0.10	0.55	0.88	0.3897	0.18
3	4.13	0.52	4.33	0.60	0.20	0.38	2.61	0.0155*	0.53
4	3.65	0.75	3.96	0.53	0.30	0.42	3.58	0.0016**	0.73
5	3.90	0.50	4.17	0.67	0.26	0.51	2.52	0.0190*	0.52
Overall	4.02	0.47	4.24	0.44	0.23	0.25	4.45	0.0002***	0.91
New literacies scenarios ($n = 24$)									
1	3.07	0.77	3.77	0.61	0.70	0.68	5.07	0.0000***	1.04
2	3.68	0.72	4.17	0.56	0.48	0.46	5.10	0.0000***	1.04
3	3.78	0.64	4.43	0.57	0.65	0.39	8.12	0.0000***	1.66
4	3.04	0.80	4.03	0.48	0.99	0.54	8.96	0.0000***	1.83
5	3.23	0.98	4.02	0.60	0.79	0.75	5.17	0.0000***	1.06
Overall	3.32	0.73	4.06	0.48	0.75	0.42	8.71	0.0000***	1.78

ICT capabilities scales: 1 = problem solving; 2 = communication and metacognition; 3 = basic capabilities; 4 = analysis and production; 5 = information and internet capabilities. NLS scales: 1 = identify/recognize info; 2 = locate/manage info; 3 = evaluate info; 4 = synthesize/answer; 5 = communicate answers

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Table 10 Student ICT capabilities ($n = 1{,}050$) and new literacies scenarios results: before PD and after PD and after PD − before PD

	Before PD		After PD		Difference: after PD − before PD				Effect size
	Mean	SD	Mean	SD	Mean	SD	t	p Value	
Scale									
1	3.96	0.63	4.09	0.67	0.13	0.73	5.84	0.0000***	0.18
2	4.07	0.67	4.17	0.65	0.10	0.76	4.34	0.0000***	0.13
3	3.87	0.72	4.04	0.74	0.17	0.79	7.19	0.0000***	0.22
4	3.78	0.75	3.95	0.74	0.17	0.79	7.08	0.0000***	0.22
5	3.57	0.78	3.83	0.79	0.25	0.85	9.87	0.0000***	0.30
Overall	3.82	0.60	3.99	0.61	0.18	0.62	9.28	0.0000***	0.29
New literacies scenarios ($n = 1{,}050$)									
1	3.14	0.91	3.64	0.90	0.49	0.99	16.31	0.0000***	0.50
2	3.29	0.97	3.82	0.85	0.52	0.98	17.26	0.0000***	0.53
3	3.04	0.98	3.62	0.96	0.58	1.08	17.48	0.0000***	0.54
4	2.88	0.97	3.84	0.87	0.56	0.92	19.87	0.0000***	0.61
5	3.37	0.97	3.84	0.87	0.56	0.92	19.87	0.0000***	0.61
Overall	3.11	0.90	3.70	0.82	0.59	0.90	20.76	0.0000***	0.64

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Table 11 CRT overall and standard-level results

Group	n size	Mean	SD	t	p value/effect size
Percent correct					
Intervention	1,153	76.9	16.4	2.8	0.0046**
Control	1,146	74.8	19.2		0.12
Total scaled score					
Intervention	1,153	167.8	9.8	2.1	0.0409*
Control	1,146	166.9	11.4		0.09
Standard I					
Intervention	1,153	72.9	19.7	2.7	0.0074**
Control	1,146	70.6	21.6		0.11
Standard II					
Intervention	1,153	83.3	16.9	3.5	0.0005***
Control	1,146	80.6	20.2		0.15
Standard III					
Intervention	1,153	78.2	19.8	0.7	0.4882
Control	1,146	77.6	21.5		0.03
Standard IV					
Intervention	1,153	75.2	17.7	3.7	0.0002***
Control	1,146	72.2	20.9		0.15

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

disappeared, indicating that the non-white students were at least somewhat responsible for any differences found overall. Evidence from this can be seen in the consistently higher average achievement of the non-white students from intervention students in comparison with the non-white control students. When low-income students from intervention and control teachers were compared in Table 13, almost all of the significance found overall remained demonstrating the low-income students from intervention classrooms performed significantly higher than low-income students from control classrooms. This indicated that low-income students might be receiving the biggest benefit from their teachers' participation in the project.

Discussion

Like the findings section, the discussion section is organized by the research questions. Beyond this, another section follows the discussion of the research questions to examine the connection between the findings from the research questions as they relate to the PD model investigated.

Research Question 1 What is the impact of 1 year of professional development on:

(a) reformed-based and technology-integrated instruction?
(b) teacher learning?
(c) teacher and student new literacies skills and ICT capabilities?

Reformed-Based and Technology-Integrated Instruction

Both the RTOP and TUSI are consistent with national standards documents, which prioritize teaching science as inquiry that is grounded in constructivist principles. TUSI was also designed to measure the extent to which technology is being

Table 12 CRT overall and standard-level results: white versus non-white comparisons

White						Non-white					
Group	*n* size	Mean	SD	*t*	*p* value/effect size	Group	*n* size	Mean	SD	*t*	*p* value/effect size
Percent correct						*Percent correct*					
Intervention	1,100	77.4	16.2	0.4	0.6596	Intervention	53	67.0	18.2	1.1	0.2935
Control	956	77.0	17.5		0.02	Control	190	63.4	22.9		0.16
Total scaled score						*Total scaled score*					
Intervention	1,100	168.1	9.8	0.2	0.8494	Intervention	53	162.2	9.1	0.9	0.3709
Control	956	168.2	11.4		0.01	Control	190	160.6	12.4		0.14
Standard I						*Standard I*					
Intervention	1,100	73.4	19.6	0.8	0.4366	Intervention	53	63.8	20.3	1.0	0.3227
Control	956	72.7	20.2		0.03	Control	190	60.2	25.3		0.15
Standard II						*Standard II*					
Intervention	1,100	83.6	16.8	1.1	0.2846	Intervention	53	75.6	18.3	1.8	0.0812
Control	956	82.8	18.3		0.05	Control	190	69.2	24.9		0.27
Standard III						*Standard III*					
Intervention	1,100	78.7	19.3	1.6	0.0.1217	Intervention	53	67.0	25.7	0.5	0.6307
Control	956	80.0	19.8		−0.07	Control	190	65.1	25.3		0.07
Standard IV						*Standard IV*					
Intervention	1,100	75.7	17.5	1.5	0.1246	Intervention	53	64.1	19.2	0.9	0.3625
Control	956	74.5	19.5		0.07	Control	190	60.8	23.6		0.14

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

Table 13 CRT overall and standard-level results: high versus low socioeconomic

High socioeconomic						Low socioeconomic					
Group	*n* size	Mean	SD	*t*	*p* value/effect size	Group	*n* size	Mean	SD	*t*	*p* value/effect size
Percent correct						*Percent correct*					
Intervention	956	78.6	15.3	1.4	0.1758	Intervention	197	68.5	19.0	2.2	0.0275*
Control	908	77.6	17.0		0.06	Control	238	64.0	22.8		0.21
Total scaled score						Total scaled score					
Intervention	956	168.8	9.3	0.6	0.5297	Intervention	1,153	163.2	10.7	2.0	0.0434*
Control	908	168.5	10.5		0.03	Control	1,146	161.0	12.4		0.20
Standard I						*Standard I*					
Intervention	956	74.7	18.6	1.7	0.0851	Intervention	1,153	64.2	22.7	1.5	0.1364
Control	908	73.2	20.2		0.08	Control	1,146	60.8	24.2		0.14
Standard II						*Standard II*					
Intervention	956	84.6	16.1	1.7	0.0918	Intervention	1,153	77.0	19.3	3.1	0.0021**
Control	908	83.2	17.9		0.08	Control	1,146	70.3	24.7		0.30
Standard III						*Standard III*					
Intervention	956	80.1	18.4	0.7	0.4607	Intervention	1,153	69.0	23.1	1.4	0.1577
Control	908	80.7	19.1		−0.03	Control	1,146	65.6	25.6		0.14
Standard IV						*Standard IV*					
Intervention	956	77.1	16.8	2.3	0.0213*	Intervention	1,153	66.2	19.3	2.4	0.0155*
Control	908	75.1	19.0		0.11	Control	1,146	61.1	23.9		0.23

* $p \leq 0.05$; ** $p \leq 0.01$; *** $p \leq 0.001$

integrated in classrooms in alignment with reformed-based science teaching and learning and has been proposed as a one measure of TPACK in reformed-based science instruction. Examples of indicators within these instruments that demonstrate the kinds of shifts targeted in instruction are as follows: RTOP students made predictions, estimations, and/or hypotheses and devised means for testing them; TUSI students use technology to display data in a way that helps them formulate conclusions. As can be seen in Table 6, participants made significant improvements in their instruction overall on both instruments and on all constructs. Additionally, as can be seen in Table 7, not only did participants make significant improvement in their instruction overall when comparing pre- and post-classroom observations, after 1 year of PD significant positive differences were also found when comparing the intervention group after PD to the delayed-treatment control group prior to PD. This offers additional evidence of the impact of the PD on instruction, since when comparing instruction of intervention teachers prior to engaging in PD to instruction of the delayed-treatment control group prior to PD (see Table 5), no original significant differences were noted.

For the intervention group (Table 5), with respect to reformed-based instruction, before participation in the professional development, while the indicators for reformed instruction were observable, the overall average mean score on each scale and overall suggested that the types of instruction sought in recent standards documents happened infrequently at best (i.e., average mean for RTOP was 1.77). In our previous research, a participant, who was also a participant in this study, shared the following that helps explain these pre-PD findings:

> My biggest gains [in the PD] came from learning how to teach using inquiry. I didn't really do inquiry before… and now I do it often. I had always been taught that inquiry was the thing I should be striving for, but I had never seen it in action or had anyone explain to me how to implement it (Campbell et al. 2014, p. 1840).

Conversely, at the end of 1 year of PD, while there still existed room for even more alignment with reformed-based instruction, evidence could be found (i.e., average mean for RTOP was 2.69) to suggest that participants' instruction was more often aligned with reformed instruction described in the RTOP (e.g., lesson encouraged students to seek and value alternative modes of investigation or of problem solving or students were encouraged to generate conjectures, alternative solution strategies, and ways of interpreting evidence). Our findings here, with respect to PD having a positive impact on teachers propensity to enact reformed-based instruction, also align with findings of others (e.g., Rushton et al. 2011).

With respect to integrating technology into science instruction before PD, as evidenced by TUSI ratings, participants were seldom found integrating technology in ways aligned to reformed-based instruction (i.e., average mean for TUSI was 0.35); something explained by one participant in our previous research:

> I… use technology, but have never done so in such an integrated way. For a long time I have been trying to imagine my ideal classroom but have been struggling how to put all of the pieces together in an effective way (Campbell et al. 2013, p. 12)

These findings regarding the ways in which participants used technology in science instruction prior to PD aligned with what others have found (e.g., Baylor and Ritchie 2002; Lim and Chai 2008). As an example, Bell et al. (2013) describe how technology has traditionally not being used to support reformed-based instruction. But, after 1 year of PD, just as with reformed-based instruction, while there still existed room for integrating technology into science instruction in ways even more aligned to reformed-based instruction, some evidence could be found (i.e., average mean for TUSI was 2.15) to suggest that participants' instruction more often integrated technology in ways aligned with TUSI (e.g., students engage in technology and use it for observing and data collecting or technology is used to help students collaborate in building their knowledge of science and scientific inquiry). Some explanations for how participants began to envision and integrate technology in science instruction as a result of participation in the PD were shared by participants in our previous research:

- I feel like technology is used best when students can use it to virtually collect data and then present it with ICTs.
- Students can also see in real time how charts and graphs change as data are put into a data table.
- It [technology-Google Docs specifically] is also a way for them to organize data that they collect in other class investigations and a way to communicate or collaborate with their work groups or with me [the teacher] (Campbell et al. 2014, p. 1835)

Koehler and Mishra (2005), as well as other researchers (e.g., Campbell and Abd-Hamid 2013; Crippen 2012; Niess 2005; Pamuk 2012), have identified how TPACK takes into account another realm of teacher knowledge (i.e., technology) and considers the role TPACK plays in teachers' conceptualization and enactment of instruction in classrooms. While more research is certainly needed to learn more about the decisions teachers in this study are making about using technological resources in science instruction, these findings, especially significant improvements in TUSI ratings recorded through classroom observations when comparing before and after

1 year of PD, provide initial evidence of teachers' developing TPACK for reformed-based science teaching that moves beyond the more commonly found traditional applications of technology in science classrooms described by Bell et al. (2013), Campbell et al. (2013), and Hsu and Wang (2013).

Overall, the results reported here are positive and demonstrate a promising change in instruction aligned with outcomes targeted by the PD. Additionally, these findings begin to provide the needed documentation of the impact of professional development on teaching practice that Roth et al. (2011) suggested are desperately needed.

Teacher Learning

Just as documentation of the impact of professional development on teaching practice is needed, so also is documentation of teacher learning. And, while most PD targets teacher learning, it is often the case that this aspect of PD goes undocumented. As is seen in Table 8, in addition to targeting changes in teaching practice and student achievement, the PD investigated in this research targeted both participants' science content and preparedness to engage in practices consistent with the nature of science. Care must be taken here in making claims regarding these findings since self-reporting surveys were used, but as described earlier, the fact that a retrospective pre- to post-approach was employed was seen as useful, especially since respondents are likely to change their perceptions of initial knowledge/preparedness as they learn more about a topic (Goedhart and Hoogstraten 1992; Howard et al. 1979; Klatt and Taylor-Powell 2005; Lamb 2005; Pratt et al. 2000). As can be seen in Table 8, the participants reported significant gains in the science content addressed in the workshop (i.e., mean of 73.25 prior and mean of 93.42 after PD). This is important since the science content addressed in the workshop was the content focus of the curriculum materials that served as a learning anchor for teachers during the PD. And, these curriculum materials later served as a resource to support instruction in the classroom with students during the academic year. An abundance of research can be found documenting the importance of teachers' content knowledge in supporting student learning (e.g., Sadler et al. 2013). As an example, among other things, Sadler et al. (2013) found that teachers' subject matter knowledge could account for higher student gains on standardized assessments. Therefore, given the alignment between the science content focus of the PD workshop and the curriculum materials teachers were asked to appropriate in the classroom during the academic year, the gains in teacher content identified are promising, especially since these content learning gains have the potential to influence student achievement, something that was also investigated and found occurring in this research.

With respect to learning gains found when considering participants' preparedness to engage in practices consistent with the nature of science (i.e., mean of 69.11 prior and mean of 93.48 after PD), because of the importance of the nature of science in science instruction (c.f., Achieve Inc. 2013; NRC 1996, 2012), this too holds potentially important implications for the instruction participants will facilitate. Additionally, these findings mirror the findings from qualitative research also completed alongside this research in this NSF funded project, whereby project participants were found developing more sophisticated understandings of the nature of science during the year of PD (Campbell et al. 2014). More specifically, participants were found moving from naïve conceptions of the nature of science focused on getting the "right answers" associated with natural realism to more sophisticated conceptions focused on the empirical nature of science, understanding science as a way of thinking and problem solving, and the tentativeness of science (Campbell et al. 2014). Examples of essential basic understandings of the nature of science highlighted in the Next Generation Science Standards identify are as follows: scientific investigations use a variety of methods, scientific knowledge is based on empirical evidence, scientific knowledge is open to revision in light of new evidence (Achieve Inc. 2013, Appendix H, p. 4). If teachers are to help students develop these essential understandings, it is important that attention is given to teachers' development of these understandings. More to the point, research like Campbell et al. (2013), Duschl (1990), and Lederman (1992) describe how when teachers' beliefs about the nature of science are revealed, in many cases they are less satisfying than what is expected. But, like the findings revealed here, others have found that teacher learning about the nature of science can be supported by PD, if the PD model engages teachers in instruction that aligns with the work of scientists and if explicit discussion and reflection are given to these essential nature of science understandings (e.g., Ackerson et al. 2009).

Teacher and Student New Literacies Skills and ICT Capabilities

As revealed earlier, among other things, in reviewing the literature related to technology-focused PD, Lawless and Pellegrino (2007), Gerard et al. (2011), and Higgins and Spitulnik (2008) described how their review provided only limited insight into the impacts technology-focused professional development had on teacher development. The findings in Table 9 provide additional documentation of the impacts of the technology-focused professional development in teacher development examined in this research. Specifically, these findings reveal teacher participants' facility in using ICTs to accomplish meaningful tasks they may encounter when engaging in science-related activities in communities of practices. As noted in Table 9, teacher participants' reported significantly higher facility with new literacies, both overall and related to each of the sub-constructs. This indicated that teachers reported increased facility in using ICTs to (a) identify research questions, recognize information relevant to the problems, (b) locate information relevant to the problems and managing information located, (c) evaluate the usefulness of the data collected, (d) synthesize information and produce information to answer questions, and (e) communicate and share research findings with others (Leu et al. 2004). These findings are important since as we noted earlier, technology is shaping or reshaping lives and society [e.g., fixtures in youth culture (Ito et al. 2008), leading to new science fields (Hey et al. 2009), and transforming science practices (Sabelli 2006)]. Therefore, ensuring that teachers are better prepared to teach, learn, and solve scientific and societal problems with technologies is essential if they are going to foster students' new literacies.

When considering ICT capabilities more specifically, teachers reported increased facility overall, and for some, but not all of the sub-constructs. So, with respect to teacher participants' technical and cognitive capabilities with ICTs, significant increases were reported for basic ICT capabilities, analysis and production with ICTs, and information- and internet-related skills. The two sub-constructs related to teacher participants' technical and cognitive capabilities with ICTs that were not found increasing significantly were problem solving and communication and metacognition. When teachers' initial reported capabilities are examined, it can be seen that these also increased, but they were already reported as quite high prior to the PD (i.e., problem solving = 4.28/5.00 and communication and metacognition = 4.41/5.00). So, teachers came to the PD with confidence in their capabilities related to these sub-constructs. In the end, these findings suggest that teachers' facility with ICTs specifically related to how they may be used productively in civic life increased and that this is at least an initial step toward them beginning to successfully cultivate their students' facility with ICTs in the context of science instruction, which is something also examined in this research and discussed next.

In addition to calls for PD research to examine teacher learning and teacher practices, Roth et al. (2011), among others, also call for PD research to examine student learning. Student learning in this research was examined both with respect to the extent to which they were developing new literacies and ICT capabilities and, as will be discussed in the next section, student achievement. With respect to new literacies and ICT capabilities, as seen in Table 10, significant increases overall for both new literacies and ICT capabilities were found, and this was also the case when considering the sub-constructs for both. These findings are promising, especially when considered alongside the significant gains observed for their teachers who engaged in the PD.

Research Question 2 What is the impact of typical instruction versus professional development model supported instruction on student achievement?

Among the findings of this research, those related to student achievement emerged as the most salient. This is seen as significant positive differences overall and for each of the standards targeted with the curriculum modules used to anchor PD were found for the students of participant teachers (intervention) when compared to students of non-participating delayed-treatment teachers (control) (Table 11). And, perhaps even more compelling, are the findings suggesting that non-white students (Table 12) and low socioeconomic students (Table 13) were found contributing more to the significant positive differences identified. This is especially compelling since the non-white students and low socioeconomic students were much smaller groups exerting a greater influence on the overall positive student achievement differences found when compared to the larger groups of white students and high socioeconomic students (i.e., non-white = 53/190 vs. white = 1,100/956; low socioeconomic = 197/238 vs. high socioeconomic = 956/908). The fact that non-white students seem to be benefiting most, as an outcome of their teachers' participation in the PD project investigated in this research, seems aligned to other research investigating inquiry-based instruction in comparison with traditional or commonplace science instruction. This is seen in Wilson et al. (2010) as they investigated the effects and equity of inquiry based and commonplace science teaching. In their research, students in inquiry-based groups reached significantly higher achievement compared to those students experiencing commonplace instruction. Additionally, they found that the commonplace instruction they investigated resulted in detectable achievement gaps by race, while the inquiry-based instruction did not (Wilson et al. 2010). With respect to low-income students, findings comparable to those reported here were reported by Lynch et al. (2005), where they found that students receiving inquiry-based instruction outperformed comparison groups, regardless of socioeconomic status, among other things. What makes our findings unique and important is that our research connects this student achievement to teachers participation in the PD model investigated in this research, while Wilson et al. (2010) and Lynch et al. (2005) were not focused on PD, but instead were more concerned with inquiry-based instruction and curriculum more generally as the intervention.

Research Questions Findings and Their Implications for the Hybridized Science Content-Pedagogy-Curriculum Material-Driven Orientation PD Model Being Investigated

As was described earlier, the PD model theory of action proposes that that as teacher participants engage as learners in the project developed curriculum and subsequently enact the curriculum in their classrooms, their content and pedagogical knowledge will be enhanced so that teacher learning, teaching practice and student learning are improved, both within and beyond the project curriculum modules anchoring the PD. The theory of action goes on to assert that evidence of the efficacy of the PD model will be found in proxies for teacher learning, teacher practice, and student learning. The result presented in Research Question 1 and Research Question 2 begins to provide the initial promise of the PD model. This was seen, as some evidence of teacher learning was found for teachers in the retrospective pre- to post-surveys that revealed participant-reported significant gains in the science content addressed in the workshops. Evidence supporting the promise of the PD model positively impacting teacher learning was also found as teacher participants' reported higher facility in using ICTs and with new literacies. With respect to teacher practice, initially promising evidence of the efficacy of the PD model positively shaping instruction as measured by classroom observations was found as participants' instruction was more aligned with reformed-based instruction and as technology was found being integrated in science instruction in ways more aligned with reformed-based instruction.

When considering student learning, initial promising evidence of the efficacy of the PD model was found as teacher participants' students reported higher facility in using ICTs and with new literacies at the end their teachers' engagement in 1 year of PD. Evidence of the efficacy of the PD model for improving student learning was also found as significant positive differences in student achievement were identified, both for the standards targeted by the curriculum modules and beyond. In summary, while care must be taken at the stage, since only 1 year of the 2-year PD module is being investigated, the collection of evidences investigated and presented support the promise of the PD model.

Conclusion, Implications, and Future Research

This research was undertaken to examine a professional development model focused on enhancing teacher and student learning by using information and communication technologies (ICTs) for engaging students in reformed-based instruction. The research is important because of its focused on the important connections between teachers' participation in professional development, changes in teaching practice, and student achievement (Higgins and Spitulnik 2008; Roth et al. 2011). Additionally, and more specifically, this research was important because of the needed focus on how teacher's pedagogy and development change as a result of engagement in technology-enhanced science teacher PD (Gerard et al. 2011; Higgins and Spitulnik 2008; Lawless and Pellegrino 2007). As was revealed in the findings section, this research provided important evidence, demonstrating that the PD model examined shows promise in supporting teachers' learning and practice. With respect to students, this research demonstrates the promise of the PD model examined specifically and reformed-based and technology-integrated instruction more broadly, for all students in the population examined. And, perhaps most saliently, this research demonstrated the initial promise for how low socioeconomic student populations and the non-white populations seem to be benefiting most from their teacher's participation in the PD model examined.

This research originated in 2010 as the authors proposed a vision for PD-supported technology integration in science instruction (Campbell et al. 2010) and subsequently received funding to test the assumptions inherent in the proposed framework. This current research is a result of our continuing work, but is seen as only the next step in the important process of examining the complexities of professional development. As an example, through using curriculum modules as anchors for PD to support teacher learning that teachers also take into their classrooms in their work with students, variations in how teachers appropriate these resources have been recognized. This has led the authors to consider how teachers' orientations shape and are shaped by PD (Campbell et al. 2013, 2014) and what factors impact what, why, and how teachers enact learning from professional development (PD). Future research planned will also look at the impact of a second year of PD that builds on the initial year examined in this research. Finally, these findings are interrelated with the work of others examining PD more broadly and the impacts technology-focused professional development specifically. We submit them here to add to current literature in these areas, while also exposing them for further scrutiny.

References

Achieve Inc (2013) Next generation science standards. www.nextgenscience.org/next-generation-science-standards

Ackerson VL, Cullen TA, Hanson DL (2009) Fostering a community of practice through a professional development program to improve elementary teachers' views of nature of science and teaching practice. J Res Sci Teach 46(10):1090–1113

Akerson V, Hanuscin DL (2007) Teaching nature of science through inquiry: results of a 3-year professional development program. J Res Sci Teach 44:653–680

American Association for the Advancement of Science (1989) Science for all Americans. Oxford University Press, New York

Anastopoulou S, Sharples M, Ainsworth S, Crook C, O'Malley C, Wright M (2012) Creating personal meaning through technology-supported science inquiry learning across formal and informal settings. Int J Sci Educ 34(2):251–273

Baylor A, Ritchie D (2002) What factors facilitate teacher skill, teacher morale, and perceived student learning in technology using classrooms? Comput Educ 39(4):395–414

Bell RL, Maeng JL, Binns IC (2013) Learning in context. Technology integration in a teacher preparation program informed by situated learning theory. J Res Sci Teach 50(3):348–379

Birman B, Desimore L, Porter A, Garet M (2000) Designing professional development that works. Educ Leadersh 57(8): 28–33

Bull G, Bell L (2009) TPACK: a framework for the CITE journal. Contemp Issues Technol Teach Educ 9(1). Retrieved from http://www.citejournal.org/vol9/iss1/editorial/article1.cfm

Campbell T, Abd-Hamid N (2013) Technology use in the science Instruction (TUSI): technology and science education reform. J Sci Educ Technol 22(4):572–588

Campbell T, Neilson D (2009) Student ideas and inquiries: investigating friction in the physics classroom. Science Activities: Classroom Projects and Curriculum Ideas 46(1):13–16

Campbell T, Longhurst M, Duffy AM, Wolf PG, Shelton BE (2013) Science teaching orientations and technology-enhanced tools for student learning in science. Res Sci Educ 43(50):2035–2057

Campbell T, Wang S, Hsu H, Duffy A, Wolf P (2010) Learning with web tools, simulations, and other technologies in science classrooms. J Sci Educ Technol 19(5):505–511

Campbell T, ZuWallack BA, Longhurst M, Shelton BE, Wolf PG (2014) An examination of the changes in science teaching orientations and technology-enhanced tools for student learning in the context of professional development. Int J Sci Educ 36(11):1815–1848

Carlone H, Webb S (2006) On (not) overcoming our history of Hierarchy: complexities of university/school collaboration. Sci Educ 90(3):544–568

Clark DB, Sampson V (2008) Assessing dialogic argumentation in online environments to relate structure, grounds, and conceptual quality. J Res Sci Teach 45(3):293–321

Cohen J (1988) Statistical power analysis for the behavioral sciences, 2nd edn. Erlbaum, Hillsdale

Crippen KJ (2012) Argument as professional development: impacting teacher knowledge and beliefs about science. J Sci Teach Educ 23:847–866. doi:10.1007/s10972-012-9282-3

Davis EA, Krajcik JS (2005) Designing educative curriculum materials to promote teacher learning. Educ Res 34(3):3–14

Duschl RA (1990) Restructuring science education. Teachers College Press, New York

Ebenezer J, Osman NK, Devairakkam L (2011) Engaging students in environmental research projects: perceptions of fluency with innovative technologies and levels of scientific inquiry abilities. J Res Sci Teach 48(1):98–116

Garet MS, Porter AC, Desimone L, Birman BF, Yoon KS (2001) What makes professional development effective? Results from a national sample of teachers. Am Educ Res J 38(4):915–945. doi:10.3102/00028312038004915

Gerard LF, Varma K, Corliss SB, Linn MC (2011) Professional development for technology-enhanced inquiry science. Rev Educ Res 81(3):408–448

Goedhart H, Hoogstraten J (1992) The retrospective pretest and the role of pretest information in evaluation studies. Psychol Rep 70:699–704

Hawley WD, Valli L (1999) The essentials of effective professional development: a new consensus. In: Sykes G, Darling-Hammond L (eds) Teaching as the learning profession: handbook of policy and practice. Jossey Bass, San Francisco, pp 127–150

Hey T, Tansley S, Tolle K (eds) (2009) The fourth paradigm: data intensive scientific discovery. Microsoft Research, Redmond

Higgins TE, Spitulnik MW (2008) Supporting teachers' use of technology in science instruction through professional development: a literature review. J Sci Educ Technol 17:511–521

Howard GS, Ralph KM, Gulanick NA, Maxwell SE, Nace D, Gerber SL (1979) Internal invalidity in pre-test–posttest self report evaluations and the re-evaluation of retrospective pretests. Appl Psychol Meas 3(1):1–23

Hsu H-Y, Wang S-K (2013) Human impact on water quality: conducting inquiry activities with cyberdatabases and ICTs. Sci Scope 37(3):37–43

Hsu H-Y, Wang S-K, Runco L (2013) Middle school science teachers' confidence and pedagogical practice of new literacies. J Sci Educ Technol 22(3):314–324

Ito M, et al (2008) Living and learning with new media: summary of findings from the digital youth project. Retrieved from http://digitalyouth.ischool.berkeley.edu/files/report/digitalyouth-WhitePaper.pdf

Johnson CC, Kahle JB, Fargo JD (2006) A study of the effect of sustained, whole-school professional development on student achievement. J Res Sci Teach 44:775–786

Klatt J, Taylor-Powell E (2005) Synthesis of literature relative to the retrospective pretest design. Paper read at the American Evaluation Association at Toronto, Ontario

Koehler M, Mishra P (2005) What happens when teachers design educational technology? The development of technological pedagogical content knowledge. J Educ Comput Resour 32(2): 131–152

Lamb T (2005) The retrospective pretest: an imperfect but useful tool. Eval Exch XI(2). Retrieved from http://www.hfrp.org/var/hfrp/storage/original/application/d6517d4c8da2c9f1fb3dffe3e8b68ce4.pdf

Lawless KA, Pellegrino JW (2007) Professional development in integrating technology into teaching and learning: knowns, unknowns, and ways to pursue better questions and answers. Rev Educ Res 77:575–614

Lederman NG (1992) Students' and teachers' conceptions of the nature of science: a review of the research. J Res Sci Teach 29:331–359

Lee VR, Thomas JM (2011) Integrating physical activity data technologies into elementary school classrooms. Educ Tech Res Dev 59(6):865–884

Lemke JL (2001) Articulating communities: sociocultural perspectives on science education. J Res Sci Teach 38(3):296–316

Leu DJ, Kinzer CK, Coiro J, Cammack D (2004) Toward a theory of new literacies emerging from the internet and other information and communication technologies. In: Ruddell RB, Unrau N (eds) Theoretical models and processes of reading, 5th edn. International Reading Association, Newark, pp 1568–1611

Lim CP, Chai CS (2008) Teachers' pedagogical beliefs and their planning and conduct of computer-mediated classroom lessons. Br J Educ Technol 39(5):807–828

Linn MC, Clark D, Slotta JD (2003) WISE design for knowledge integration. Sci Educ 87(4):517–538

Lowenstein R (2011) New York City public school indicators: demographics, resources, outcomes, annual report 2011. http://www.ibo.nyc.ny.us/iboreports/2011edindicatorsreport.pdf

Lussier C, Gomez S, Hurst R, Hendrick S (2007) Improving science classroom instruction by means of constructivism and technology. In: Montgomerie C, Seale J (eds) Proceedings of world conference on educational multimedia, hypermedia and telecommunications 2007. AACE, Chesapeake, pp 2282–2284

Lynch S, Kuipers J, Pyke C, Szesze M (2005) Examining the effects of a highly rated science curriculum unit on diverse students: results from a planning grant. J Res Sci Teach 42(8):921–946

Markauskaite L (2007) Exploring the structure of trainee teachers' ICT literacy: the main components of, and relationships between, general cognitive and technical capabilities. Educ Tech Res Dev 55:547–572

Mumtaz S (2000) 'Factors affecting teachers' use of information and communications technology: a review of the literature. Technol Pedagogy Educ 9(3):319–342

National Research Council (2012) A framework for K-12 science education: practices, crosscutting concepts, and core ideas. Committee on a conceptual framework for new K-12 science education standards. Board on science education, division of behavioral and social sciences and education. The National Academies Press, Washington, DC

National Research Council (NRC) (1996) National science education standards. The National Academies Press, Washington, DC

Niess ML (2005) Preparing teachers to teach science and mathematics with technology: developing a technology pedagogical content knowledge. Teach Teach Educ 21(5):509–523

Pamuk S (2012) Understanding preservice teachers' technology use through TPACK framework. J Comput Assist Learn 28:425–439

Park Rogers MA, Abell SK, Marra RM, Arbaugh F, Hutchins KL, Cole JS (2010) Orientations to science teacher professional development: an exploratory study. J Sci Teach Educ 21:309–328

Park H, Khan S, Petrina S (2009) ICT in science education: a quasiexperimental study of achievement, attitudes toward science, and career aspirations of Korean middle school students. Int J Sci Educ 31(8):993–1012

Pew Internet & American Life report (2002) Use of the internet at major life moments. http://www.pewinternet.org/reports/toc.asp?Report=58. Retrieved 9 Dec 2008

Piburn M, Sawada D, Turley J, Falconer K, Benford R, Bloom I, Judson E (2000) Reformed teaching observation protocol (RTOP): reference manual (ACEPT technical report no. INOO-3). Arizona collaborative for excellence in the preparation of teachers, Tempe, AZ (Eric Document Reproduction Service, ED 447 205)

Pratt CC, McGuigan WM, Katzev AR (2000) Measuring program outcomes: using retrospective pretest methodology. Am J Eval 21(3):341–349

Quintana C, Reiser BJ, Davis EA, Krajcik J, Fretz E, Duncan RG et al (2004) A scaffolding design framework for software to support science inquiry. J Learn Sci 13(3):337–386

Richardson V (2003) The dilemmas of professional development. Phi Delta Kappan 84(5):401–406

Roth KJ, Garnier HE, Chen C, Lemmens M, Schwille K, Wickler N (2011) Videobased lesson analysis: effective science PD for teacher and student learning. J Res Sci Teach 48(2):117–148

Rushton GJ, Lotter C, Singer J (2011) Chemistry teachers' emerging expertise in inquiry teaching: the effect of a professional development model on beliefs and practice. J Sci Teach Educ 22(1):23–52

Sabelli NH (2006) Complexity, technology, science, and education. J Learn Sci 15(1):5–9

Sadler PM, Sonnert G, Coyle HP, Cook-Smith N, Miller JL (2013) The influence of teachers' knowledge on student learning in middle school physical science classrooms. Am Educ Res J 50(5):1020–1049

Shulman LS (1986) Those who understand: knowledge growth in teaching. Educ Res 15(2):4–14

Singer J, Marx RW, Krajcik JS, Clay-Chambers J (2000) Constructing extended inquiry projects: curriculum materials for science education reform. Educ Psychol 35(3):165–178. doi:10.1207/S15326985EP3503_3

Slater SJ, Slater TF, Shaner A (2008) Impact of backwards faded scaffolding in an astronomy course for pre-service elementary teachers based on inquiry. J Geosci Educ 56:408–416

Soong B, Mercer N (2011) Improving students' revision of physics concepts through ICT-based co-construction and prescriptive tutoring. Int J Sci Educ 33(8):1055–1078

Squire K (2006) From content to context: videogames as designed experience. Educ Res 35(8):19–29

Stein M, Smith M, Silver E (1999) The development of professional developers: learning to assist teachers in new settings in new ways. Harvard Educ Rev 69(3):237–269

U.S. Census Bureau (2010) Diversity. Retrieved Jan 2015, from http://www.census.gov/2010census/popmap/ipmtext.php?fl=49

Utah State Office of Education (USOE) (2007) Utah performance assessment system for students. Retrieved 14 Dec 2007, from Utah Performance Assessment System for Students. http://64.233.169.104/search?q=cache:rzO5weK-SUoJ:www.schools.utah.gov/eval/DOCUMENTS/Science_ItemWritingAnnouncementiRegister.pdf+Utah+CRT&hl=en&ct=clnk&cd=5&gl=us&client=firefox-a

Varma K, Husic F, Linn MC (2008) Targeted support for using technology-enhanced science inquiry models. J Sci Educ Technol 17:341–356. doi:10.1007/s10956-008-9104-8

Williams M, Linn MC, Ammon P, Gearhart M (2004) Learning to teach inquiry science in a technology-based environment: a case study. J Sci Educ Technol 13(2):189–206. doi:10.1023/B:JOST.0000031258.17257.48

Wilson CD, Taylor JA, Kowalski SM, Carlson J (2010) The relative effects and equity of inquiry-based and commonplace science teaching on students' knowledge, reasoning, and argumentation. J Res Sci Teach 47(3):276–301

Wu H (2010) Modelling a complex system: using novice-expert analysis for developing an effective technology-enhanced learning environment. Int J Sci Educ 32(2):195–219

Zhao Y, Cziko GA (2001) Teacher adoption of technology: a perceptual control theory perspective. J Technol Teach Educ 9(1):5–30