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Teacher learning in technology professional development and its impact on student achievement in science

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ABSTRACT
This research investigated teacher learning and teacher beliefs in a two-year technology professional development (TPD) for teachers and its impact on their student achievement in science in the western part of the United States. Middle-school science teachers participated in TPD focused on information communication technologies (ICTs) and their applications in science inquiry pedagogy. Three self-reporting teacher instruments were used alongside their student achievement scores on the end-of-year state-science-test. The teacher self-reporting measures investigated technological literacy, ICT capabilities, and pedagogical beliefs about science inquiry pedagogy. Data were collected every year, and descriptive statistics, *t*-tests, and Pearson's correlations were used for analysis. We found teachers' technological skills and ICT capabilities increasing over time with significant gains each year. Additionally, teachers' pedagogical beliefs changed to become more science inquiry oriented over time; however, the gains were not significant until after the second year of TPD. Comparisons of teacher learning and belief measures with student achievement revealed that the students' performance was correlated to teachers' pedagogical beliefs about science inquiry, but not to their technological skills nor to their ICT capabilities. This research suggests that pedagogical considerations should be foregrounded in TPD and that this may require more longitudinal TPD to ensure that technology integration in science instruction is consequential to student learning.

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Technology professional development; teacher learning; teacher beliefs; science inquiry; student achievement

Researchers (e.g. Gerard, Varma, Corliss, & Linn, 2011) and funding agencies (e.g. National Science Foundation) have recognised the importance of teaching science with technology in K-12 classrooms. This recognition has, among other things, led to increases in technology professional development (TPD) opportunities for teachers to support the meaningful integration of technology into disciplinary contexts. According to Hughes (2005), classroom use of technology occurs in three different ways: simply replacing traditional classroom tools (replacement), assisting classroom practice in effective ways without changing original instruction (amplification), or re-conceptualising the roles of

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teachers and students in classroom practices (transformation). However, Hew and Brush (2007) note that most TPD has focused on teachers' learning to use new technology or to use it in ways supportive of amplification. In this, only a limited emphasis has been placed on how technology can transform traditional structures or methods of interacting in classroom (i.e. transformation). In fact, in a meta-analysis of a large number of studies (i.e. 360), it was revealed that TPD is effective in instruction when it is focused on transformation (Gerard et al., 2011).

Ertmer (1999) suggested that teachers often deal with various factors when integrating new technology into innovative pedagogy and grouped these factors into two themes, external and internal. External factors are circumstantial to teachers' contexts (e.g. lack of resources), while internal factors are those that are situated within teachers themselves (e.g. epistemological beliefs). More specifically, the internal factors are teachers' skills and abilities that are required to effectively enact new teaching practices, which are filtered and shaped by their beliefs and philosophies about teaching and learning (Lee, Feldman, & Beatty, 2012). To use technology in transformative ways, teachers must reconcile any internal conflicts between their beliefs and what they are being asked to do. TPD is one way of supporting teachers in resolving these conflicts to reimagine science teaching and learning with technology, where teachers can learn to increase their technological skills, while concurrently working to reconcile their changing pedagogical beliefs.

The ultimate goal of TPD is to enhance student learning through the use of innovative technologies effectively integrated into pedagogy that supports meaningful transformation of learning environments. However, while there are studies that report the positive impacts of using technology on students' learning (e.g. Chang, Quintana, & Krajcik, 2010; Gulek & Demirtas, 2005), what is largely missing in the literature is an understanding of how teacher learning in TPD translates into student learning in disciplinary contexts. More specifically, Blanchard, LePrevost, Tolin, and Gutierrez (2016) noted, 'there is a paucity of research linking teacher professional development, teacher beliefs and practices, and student achievement outcomes' (p. 208), something also noted by others (Higgins & Spitulnik, 2008; Lawless & Pellegrino, 2007). Given this, we investigated teachers' learning of technology and changes of pedagogical beliefs from TPD, and its associated influences on student achievement. Below, we review theoretical background of the current study.

Theoretical background

Teacher learning and professional development

Teacher learning is the process whereby teachers develop expertise over time (Kelly, 2006), and this learning happens in a complex system with various influential factors. Professional development (PD) provides teachers with knowledge and skills to enhance their teaching and to better inform their understandings of student learning. While PD is understood as individual teacher training sessions, *professional learning* includes multiple experiences of ongoing modification to conceptual, practical and philosophical stance through a multiplicity of contexts (Century, Rudnick, & Freeman, 2010; Rogers et al., 2007).

Historically, the logic model proposed for PD has been that teachers will change practice as a result of participating in some form of training (Van Duzor, 2011). Although this premise may be supported, the results of these trainings from PD frequently do not measure up to the intended outcomes (Davis & Krajcik, 2005; Guskey, 2009; Schrum, 1999). In many cases, the success of PD has been measured in terms of satisfaction surveys gathered from participating teachers (Guskey & Sparks, 1991), and studies in TPD have focused on teachers' learning of technology or finding ways to help them integrate technology into instruction (Blanchard et al., 2016; Campbell, Longhurst, Wang, Hsu, & Coster, 2015; Longhurst et al., 2016). Studies about student learning affected by technology use have been conducted for the past decades, but insights about what teachers learn from TPD and how teacher learning is related to student achievement are scarce. In fact, researchers have noted the limitations in the literature that seek to explain how teachers and ultimately students benefit from professional learning (Borko, 2004; Brinkerhoff, 2006; Guskey & Yoon, 2009). Consequently, the limited empirical evidence linking teacher learning experiences and student achievement provides a needed area of focus for ongoing investigation (Van Driel, Beijaard, & Verloop, 2001).

Teacher beliefs

Beliefs are 'part of a group of constructs that describe the structure and content of a person's thinking that are presumed to drive his/her actions' (Bryan & Atwater, 2002, p. 823). Teachers have beliefs about their abilities, their students, schools, and teaching strategies, which, among other things, constitute their identity as a teacher. Therefore, teacher beliefs are an important factor that can influence their decisions in teaching. This is noted by Bryan and Atwater (2002):

> teachers' beliefs about the teaching-learning process play a significant role in determining the nature of teachers' purposes in the classroom and directly affect many aspects of their professional work, including lesson planning, assessment, and evaluation. (p. 825)

In addition, teachers' beliefs affect their decision-making when interacting with students in classrooms (Bryan & Atwater, 2002). In other word, beliefs influence an individual's behaviour. For example, expectancy-value theory (Eccles, 1983; Feather, 1982) asserts that expected beliefs about success and how people value it affect behaviour. Bandura (1977) also noted in as part of self-efficacy theory that '[t]he strength of peoples' convictions in their own effectiveness is likely to affect whether they will attempt to cope with given situations; hence, perceived self efficacy influences choice of behavior' (p. 193). Self-efficacy is explained with two dimensions: *efficacy expectation* and *outcome expectancy* (Bandura, 1977). An efficacy expectation, often called *self-efficacy*, is a belief about one's perceived capabilities to perform a behaviour, and *outcome expectancy* is one's estimate that a certain outcome will emerge from a given action or behaviour (Bandura, 1977). Although teacher self-efficacy may not show their true capabilities, it provides some level of insight related to their behaviour (Bandura, 1977; Smolleck, Zembal-Saul, & Yoder, 2006). Bandura (1995) explained that 'people with high assurance in their capabilities in given domains approach difficult tasks as challenges to be mastered rather than as threats to be avoided' (p. 11), while people with low efficacy 'shy away from difficult tasks, which they view as personal threats' (p. 11).

Studies have investigated relations between teacher beliefs and student achievement. The *Pygmalion effect* is one widely known example of how researchers have described teacher beliefs affecting student achievement (Rosenthal, 1994; Rosenthal & Jacobson, 1966). It is explained with the *self-fulfilling prophecy* that 'a false definition of the situation evoking a new behavior which makes the originally false conception come true' (Merton, 1948, p. 195). Although its original definition is nuanced in a negative way, it is often interpreted as the power of teacher expectations affecting students. Tauber (1998) noted that, 'one's expectations about a person can eventually lead that person to behave and achieve in ways that confirm those expectations' (p. 1).

While teacher beliefs play an important role in determining teacher behaviours, possibly influencing student achievement, it is considered one of the important barriers that must be overcome when teachers are adopting new practices. In TPD, studies have reported that teachers often encounter conflicts in their beliefs when trying to integrate technology in their classrooms (Ertmer, 1999; Lee et al., 2012). More specifically, adopting innovative pedagogies that integrate technology often requires teachers to change previously held pedagogical beliefs. However, little is known about the changes of pedagogical beliefs over time as teachers participate in longitudinal TPD, especially related to its effect on student learning of science.

Teaching and learning with technology

Due to the ubiquitous use of technology in today's world, technological skills have become an essential literacy in the twenty-first century. In fact, various technologies are available that can be used in education; however, this necessitates teachers with technology capabilities. In the meta-analysis of more than 500 studies about computer-based instruction, Kulik (1994) summarised that students usually learned more, learned content in less time, and enjoyed their classes more when they received computer-based instruction. Li and Ma (2010) reported in their meta-analysis of 46 studies involving 36,793 learners that the use of computer technology resulted in significantly positive effects on student achievement. Additionally, multiple studies have documented evidence that using technology enhances student learning, achievement, and understanding of abstract concepts, as well as increasing interest about learning (Cole, 2009; Gulek & Demirtas, 2005; Lee, Linn, Varma, & Liu, 2010; Lei & Zhao, 2007; Schacter, 1999).

Although the use of technology can influence student learning, technology is often underutilised in instruction (Bell, Maeng, & Binns, 2013; Belland, 2009). In many science classes, technology may be used as a tool to support traditional instruction or simply for administrative purposes (Bell et al., 2013; Cuban, Kirkpatrick, & Peck, 2001). Recent studies argue that it is more important to know how to use technology than how much it is used. For example, Lei and Zhao (2007) noted, 'the quantity of technology use alone is not critical to student learning' (p. 284), and even warned, 'when the quality of technology use is not ensured, more time on computers may cause more harm than benefit' (p. 284).

Related to considering the quality of how technology is used, Li and Ma (2010) found in their study that the positive effect of technology on student achievement was greater when it was combined with a constructivist instruction. Further, Kim (2011) reported that students in guided inquiry instruction integrated with technology had significant gains on their attitudes towards science and content knowledge of science concepts. Additionally, Jacobson, Taylor, and Richards (2016) reported how eighth grade students experiencing an intervention whereby scientific inquiry pedagogy integrated technology had significant learning gains. Given this, in our current study, a model of TPD was provided that focused on integrating technology into scientific inquiry pedagogy. Below we review literature about scientific inquiry and teacher beliefs and practices of scientific inquiry teaching.

Beliefs and practices of science teaching and inquiry pedagogy

The National Research Council (NRC) defined scientific inquiry in the National Science Education Standards (NRC, 1996) as 'the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work' (p. 23). Scientific inquiry learning affords students the opportunity to engage in investigations to support their construction and refinement of scientific ideas and explanations over time in ways that are more representative of how professional scientists study the natural world (NRC, 1996). More recently, the NRC (2012) asserted that students should engage in the process of scientific inquiry and noted, 'students cannot comprehend scientific practices, nor fully appreciate the nature of scientific knowledge itself, without directly experiencing those practices for themselves' (p. 30). Furthermore, the NRC (2000) identified the following most essential features of classroom scientific inquiry: (1) learners engage in scientifically oriented questions; (2) learners give priority to evidence in responding to questions; (3) learners formulate explanations from evidence; (4) learners connect explanations to scientific knowledge; and (5) learners communicate and justify explanations.

While there is documentation to suggest that scientific inquiry leads to positive influences on student learning of science (Chang & Mao, 1999; Ertepinar & Geban, 1996; Hakkarainen, 2003; Shymansky, Hedges, & Woodworth, 1990), science inquiry pedagogy is described as a difficult task for many teachers (Roehrig & Luft, 2004). Science inquiry pedagogy requires students to play new roles to actively participate in sense-making activities in classrooms, as well as teachers to guide students to bring up questions about phenomena and to design and conduct their own investigations. These features of instruction are somewhat different from traditional instruction that is often teacher-centered and relies on delivery pedagogy.

Teachers' ability to engage students in scientific inquiry often necessitates them changing their pedagogical beliefs. Recognising this, a limited number of researchers have investigated the changes of teacher beliefs for those teachers who have participated in scientific inquiry-focused PD (Campbell, Abd-Hamid, & Chapman, 2010; Rienties, Brouwer, & Lygo-Baker, 2013; Riggs & Enochs, 1990; Smolleck et al., 2006). For example, Rienties et al. (2013) reported that teacher beliefs about knowledge transmission, the indicator of teacher-centered approach, decreased as teachers participated in PD. And, Smolleck et al. (2006) developed an instrument to measure teacher beliefs about the essential five features of classroom inquiry (NRC, 2000). While the studies have examined teacher beliefs and changes related to science inquiry-focused PD, these have been limited, especially since few have investigated the impact of teacher learning related to science inquiry pedagogy and its connection to student learning outcomes in science.

Given the limited explanatory power of research that has investigated teachers' changing beliefs in PD and the paucity of research linking teacher PD, teacher beliefs and practices, and student achievement outcomes (Blanchard et al., 2016; Higgins & Spitulnik, 2008; Lawless & Pellegrino, 2007), the current study investigated the following research questions: (1) How does teacher learning related to technologies change across participation in two years of TPD; (2) How does teacher learning related to pedagogical beliefs about science inquiry pedagogy change across participation in two years of TPD; and (3) In what ways can teacher learning related to technologies and science inquiry pedagogy be found connected to student achievement in science?

Method

Setting and participants

This study took place in the context of eighth grade science classrooms in public schools in suburban areas in the western part of the United States. PD was provided to three different cohorts using a delayed-treatment design, whereby participation was delayed for each subsequent cohort by a year. The content and pacing of TPD were the same for all cohorts (see Table 1). Teachers instructing eighth grade science in secondary schools were invited to participate, and a total of 36 teachers voluntarily participated in the study: 14 Cohort 1 teachers, 10 Cohort 2 teachers, and 12 Cohort 3 teachers. Among them, four teachers dropped out of the study after one year of TPD. Students of the participating teachers were included in the study. All research activity was approved by the institutional review board and conducted in accordance with the ethics requirements of each author's university. Throughout the study, identification codes were used instead of using their names in order to ensure participant confidentiality.

Professional development

The TPD included two years of learning, 120 hours total each year that included a 9-day summer and a 3-day winter workshops, and 2-hour monthly meetings during the school year. TPD was based on an *educative curriculum* that promoted teacher learning as well as student learning (Davis & Krajcik, 2005). The participating teachers played a role as learners in TPD then enacted what they had learned in their classrooms with their students. TPD was anchored with four different curriculum modules with scientific inquiry pedagogy developed by the project leadership for eighth grade science. The first module, the focus of the summer workshop during Y1, was about the *human influences on environment*, and the second module, the focus of the winter workshop during Y1, was about *energy and motion.* The third module, the focus of the summer workshop during Y2, was about the *ecological factors affecting plants*, and the fourth module, the focus of the winter workshop during Y2, was about the *nature of matter*. The teachers enacted modules 1 and 2 in their classrooms during Y1, and all modules 1, 2, 3, 4 during Y2. More information about all modules and TPD activities can be found in Table 1.

Each module was implemented using the *backwards faded scaffolding inquiry approach*, whereby students engaged in multiple investigations within each module with increasing levels of independence in each successive inquiry (Slater, Slater, & Shaner, 2008). In other words, the iterative process enabled students to participate in the research process as *assistants* in the first stage (e.g. a teacher leads the process and students follow the teacher's instruction), then as *co-researchers* in the second stage (e.g. students conduct

Table 1. Content and pacing of TPD (Campbell et al., 2015; Longhurst et al., 2016).

	Year	Year 1	Year 2
Focused module	Summer and Fall	Module 1: Human Influences on Environment [a]*Photo editing program, Google Earth*	Module 3: Ecological Factors Affecting Plants [a]*A virtual population community simulation (Duffy, Wolf, Barrow, Longhurst, & Campbell, 2013)*
	Winter and Spring	Module 2: Energy and Motion [a]*Video editing program*	Module 4: Nature of Matter [a]*A virtual game (Campbell et al., 2013)*
TPD description	Summer (9 Days)/Winter (3 Days) Workshop	Days 1–5/(Days 1–2 at Winter) • Teachers engage in the focused module educative curriculum with 'learner hat' on and TPD providers as instructors. • In between class period sessions, teachers with 'teacher hat' on discuss facilitation of each class period and make notes in teacher constructed instructional guide to supplement instructional notes provided in educative curriculum. Days 6–9/(Day 3 at Winter) • Prepare materials for enactment in classroom in the Fall/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 Fall/Spring.	
	Fall/Spring monthly meetings (4 × 2 hours after school)	Month 1: meeting • Revisiting principles of reformed-based instruction and new literacy. Additional time spent preparing to enact the focused module in the classroom Month 2: meeting • Reflecting on enactment of the focused module 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 the focused Module to discuss possible modifications based on enactment	
Practices		Modules 1, 2	Modules 1, 2, 3, 4

[a]In addition to the specific technology in each module, ICT technologies (such as Google Apps, spreadsheet, search engines, Youtube, Blogs) were generally used throughout all activities of TPD.

the research with teacher input together), and direct it as *lead researchers* in the last stage (e.g. students determine procedures and generate conclusions).

Instruments and data collection

Teacher data were collected with three self-reporting instruments: technological literacy (Survey A), information communication technology (ICT) capabilities (Survey B), and beliefs about science inquiry pedagogy (Survey C). They consisted of Likert-type items with five answer choices: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree. Survey A (Hsu, Wang, & Runco, 2013) consisted of 30 items, measuring teachers' technological skills of using technologies like Google Docs, spreadsheets, search engines, Google Earth, and YouTube. In this instrument, teachers responded to scenarios that required them to assess their ICT skills to resolve problems. Survey B[1] (revised version of Markauskaite, 2007) consisted of 34 items, measuring teachers' capabilities in using ICTs. Survey C (Smolleck et al., 2006) consisted of 68 items, measuring teachers' pedagogical beliefs about science inquiry in two dimensions: self-efficacy (SE) that they believe they are capable of organising and enacting teaching science as inquiry, and outcome expectancy (OE) that they expect their students to perform in class as the consequence of teaching science as inquiry. The teachers reported their responses to the surveys at baseline before participating in TPD (Y0), at the end of one year of TPD (Y1), and at the end of two years of TPD (Y2). Additional details for each instrument are provided in Table 2, along with exemplary items.

Student achievement scores on the end-of-year state-science-test (Criterion-Referenced Test, CRT) were collected from 23 Cohort 1 and 2 teachers in 2012 (Cohort 1 Y1 and Cohort 2 Y0) and in 2013 (Cohort 1 Y2 and Cohort 2 Y1). However, CRT scores were not available for Cohort 2 Y2 and Cohort 3 teachers because the state administered test was changed in 2014. Due to the different structure of the test, the comparison between the new test and the one previously administered in 2012 and 2013 was not possible. In sum, the numbers of students for which CRT data were collected included 1268 from Cohort 1 in Y1, 1114 from Cohort 1 in Y2, 1028 from Cohort 2 in Y0, and 1059 from Cohort 2 in Y1.

Analysis

In the current study, we used three different analyses. First, to understand the impact of the TPD on teacher learning and change, descriptive statistics were measured for each instrument item for each year. The results are presented as graphs showing the changes of the teachers' technological/ICT skills and pedagogical beliefs over time. Next, to investigate the significance of the changes between years, a paired-samples t-test was calculated for each survey instrument between Y1 and Y0, between Y2 and Y1, and between Y2 and Y0. In addition, effect sizes were calculated with the Cohen's d value (Cohen, 1988), which is the mean difference divided by the standard deviation, with the classification as small ($d = 0.2$), medium ($d = 0.5$) and large ($d \geq 0.8$). Finally, to examine the impact of the TPD on student achievement, descriptive statistics were measured for individual teachers for each survey and their students' CRT scores for each year, and Pearson's correlation coefficients were determined for each individual teachers' survey results compared to their students' CRT means.

Findings

Teacher learning related to technologies

Results from Surveys A and B show that teachers' technological skills and ICT capabilities increased over time (Figures 1(a, b) and 2(a, b)). The teachers became more comfortable with most aspects of using technologies and ICTs such as in creating/editing Google Docs (Figure 1(a), #1, #2 and Figure 2(a), #16), a blog/website (Figure 1(a), #18, #19, #21, #30), searching information (Figure 1(a), #3, #5, #14) sharing documents on a web (Figure 1(a), #7, #8, #10, #22), or using communication tools (emails, Skype, etc., Figure 2(a), #30). They also gained confidence using technology for difficult tasks such as using Google

Table 2. Survey instruments employed in this study.

Instrument	Description	Sample items
Survey A: technological skills (Hsu et al., 2013)	30 Likert-type items 5 answer choices[a] Measuring technological skills	I can create a document using Google Doc. I can share a Google Doc with my others to allow them to edit the document. I can export the completed video clip to YouTube. I can create a form for collecting data/ information with Google spreadsheet.
Survey B: ICT capabilities (Markauskaite, 2007)	34 Likert-type items 5 answer choices[a] Measuring ICT capabilities and its use into problem solving	I can find information and select appropriate tools for the solution of a problem. I can present a solution in a variety of forms and to different audiences. I can manipulate data and solve various problems using spreadsheets. I can publish and deliver the results of a research activity using ICT presentation tools and networks.
Survey C: pedagogical beliefs about science inquiry (Smolleck et al., 2006)	68 Likert-type items 5 answer choices[a] Measuring pedagogical beliefs about science inquiry Consisting five constructs with two dimensions: self-efficacy about science inquiry (SE) & outcome expectancy to students (OE)	*Construct A: Learner engages in scientifically oriented questions.* (SE) I possess the ability to provide meaningful common experiences from which predictable scientific questions are posed by students. (OE) I expect students to ask scientific questions. *Construct B: Learner gives priority to evidence in responding to questions.* (SE) I am able to facilitate open-ended, long-term student investigations in an attempt to provide opportunities for students to gather evidence. (OE) My students determine what evidence is most useful for answering their scientific question(s). *Construct C: Learner formulates explanations from evidence.* (SE) I am able to provide students with the opportunity to construct alternative explanations for the same observations. (OE) I require students to create scientific claims based on observational evidence. *Construct D: Learner connects explanations to scientific knowledge.* (SE) I am able to encourage my students to independently examine resources in an attempt to connect their explanations to scientific knowledge. (OE) I expect students to recognise the connections existing between proposed explanations and scientific knowledge.

(Continued)

Table 2. Continued.

Instrument	Description	Sample items
		Construct E: Learner communicates and justifies explanations. (SE) I am able to provide opportunities for my students to describe their investigations and findings to others using their evidence to justify explanations and how data were collected. (OE) I require students to defend their newly acquired knowledge during large and/or small group discussions.

[a]Five answer choices: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, and (5) strongly agree.

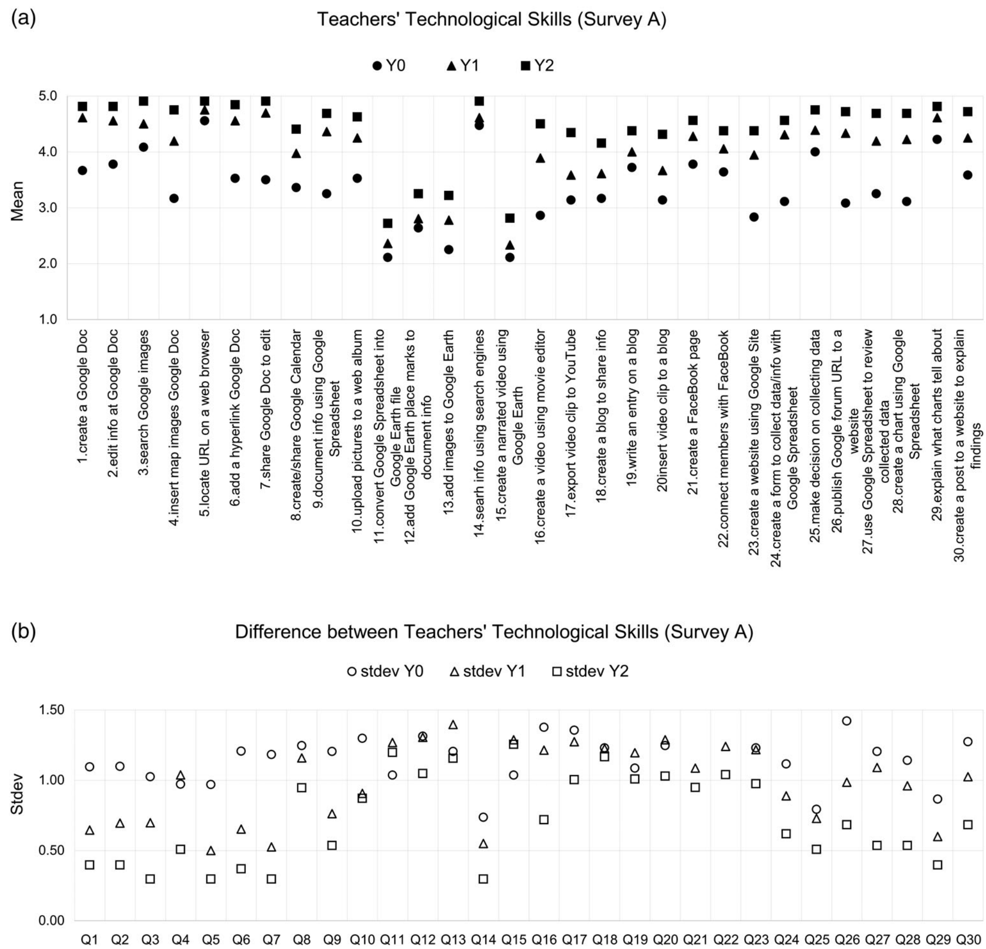

Figure 1. (a) Teachers' technological skills over time (Survey A). (b) Difference between teachers on their technological skills (Survey A).

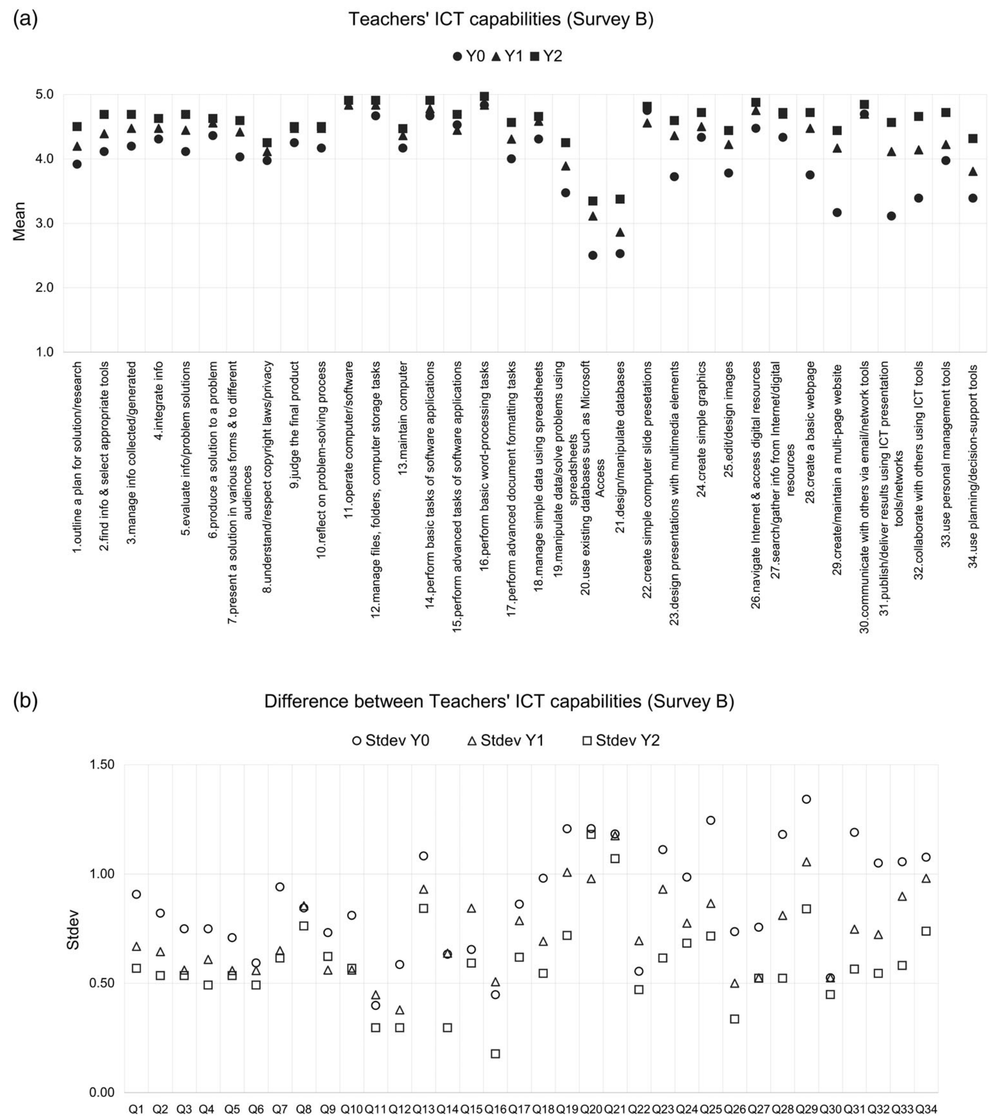

Figure 2. (a) Teachers' ICT capabilities over time (Survey B). (b) Difference between teachers on their ICT capabilities (Survey B).

Earth (Figure 1(a), #11, 12, 13, 15) or manipulating databases for advanced application (Figure 2(a), #20, #21).

As the teachers participated in the TPD, the means for individual items increased (Figures 1(a) and 2(a)), and the standard deviations between the teachers decreased (Figures 1(b) and 2(b)). *T*-test results show that the teacher changes were significant when comparing participating years of TPD (Table 3). In Survey A, there were significant differences between baseline ($M = 3.4$, $SD = .81$) and Y1 ($M = 4.0$, $SD = .64$), $t\ (35) = 6.27$, $p < .001$; between Y1 and Y2 ($M = 4.4$, $SD = .44$), $t\ (31) = 4.42$, $p < .001$; and between baseline and Y2, $t\ (31) = 8.32$, $p < .001$. Similarly, in Survey B, there were significant differences between baseline ($M = 4.0$, $SD = .55$) and Y1 ($M = 4.3$, $SD = .44$), $t\ (35) = 4.01$, $p < .001$;

Table 3. *T*-test results of teacher surveys.

Instrument	Comparison	Differences Mean	SD	*t*	df	Sig.	Effect size
Technological skills (Survey A)	Y1–Y0	0.67	0.639	6.272	35	.000**	1.05
	Y2–Y1	0.42	0.538	4.422	31	.000**	0.78
	Y2–Y0	1.06	0.720	8.321	31	.000**	1.47
ICT capabilities (Survey B)	Y1–Y0	0.31	0.471	4.012	35	.000**	0.66
	Y2–Y1	0.21	0.420	2.857	31	.008*	0.50
	Y2–Y0	0.47	0.491	5.358	31	.000**	0.96
Pedagogical beliefs about science inquiry (Survey C)	Y1–Y0	0.16	0.521	1.829	35	.076	0.31
	Y2–Y1	0.32	0.508	3.553	31	.001*	0.63
	Y2–Y0	0.45	0.516	4.951	31	.000**	0.87
	SE: Y1–Y0	0.22	0.541	2.399	35	.022	0.41
	SE: Y2–Y1	0.29	0.530	3.063	31	.005*	0.55
	OE: Y1–Y0	0.10	0.518	1.136	35	.264	0.19
	OE: Y2–Y1	0.35	0.509	3.920	31	.000**	0.69
	Y0: SE–OE	0.13	0.225	3.326	35	.002*	0.58
	Y1: SE–OE	0.24	0.214	6.818	35	.000**	1.12
	Y2: SE–OE	0.15	0.185	4.761	31	.000**	0.81

*Significant at the .01 level (two-tailed).
**Significant at the .001 level (two-tailed).

between Y1 and Y2 ($M = 4.6$, $SD = .32$), $t\ (31) = 2.86$, $p < .01$; and between baseline and Y2, $t\ (31) = 5.36$, $p < .001$. These results indicate that the teachers reported significant gains in their technological skills and ICT capabilities in the second year of TPD, as well as in the first year of TPD. Additionally, the effect sizes ($d_{Y1-Y0} = 1.05$, $d_{Y2-Y1} = 0.78$, $d_{Y2-Y0} = 1.47$ in Survey A; $d_{Y1-Y0} = 0.66$, $d_{Y2-Y1} = 0.50$, $d_{Y2-Y0} = 0.96$ in Survey B) were medium to large. Interestingly, the effect size was larger in the first year than in the second year for both surveys, indicating the higher practical significance of learning technology in the first year than in the second year.

Pedagogical beliefs about science inquiry

Teachers' pedagogical beliefs improved in every construct of teaching science as inquiry over the two years of TPD (Figure 3(a)) and the standard deviations between the teachers decreased over time (Figure 3(b)). However, the paired-samples *t*-test results (Table 3) show that the gains were not significant between baseline ($M = 3.74$, $SD = .621$) and Y1 ($M = 3.90$, $SD = .550$). Conversely, as can be seen in Table 3, the teachers had significant changes in their pedagogical beliefs in the second year ($M = 4.20$, $SD = .489$): $t\ (31) = 3.55$, $p < .01$ between Y1 and Y2 with the effect size $d = 0.63$; and $t\ (31) = 4.95$, $p < .001$ between baseline and Y2 with the effect size $d = 0.87$. The results suggest that it takes long time for teachers to change their pedagogical beliefs.

Interestingly, the difference between SE and OE was significant every year, with SE being significantly higher than OE: $t\ (35) = 3.33$, $p < .01$ for baseline (mean for SE = 3.81, OE = 3.68); $t\ (35) = 6.82$, $p < .001$ for Y1 (mean for SE = 4.02, OE = 3.78); and $t\ (31) = 4.76$, $p < .001$ for Y2 (mean for SE = 4.28, OE = 4.13). It suggests that overall the teachers' beliefs in their capability to organise and execute teaching science as inquiry was higher than what they expected their students to perform in science inquiry class as a result of teaching science as inquiry.

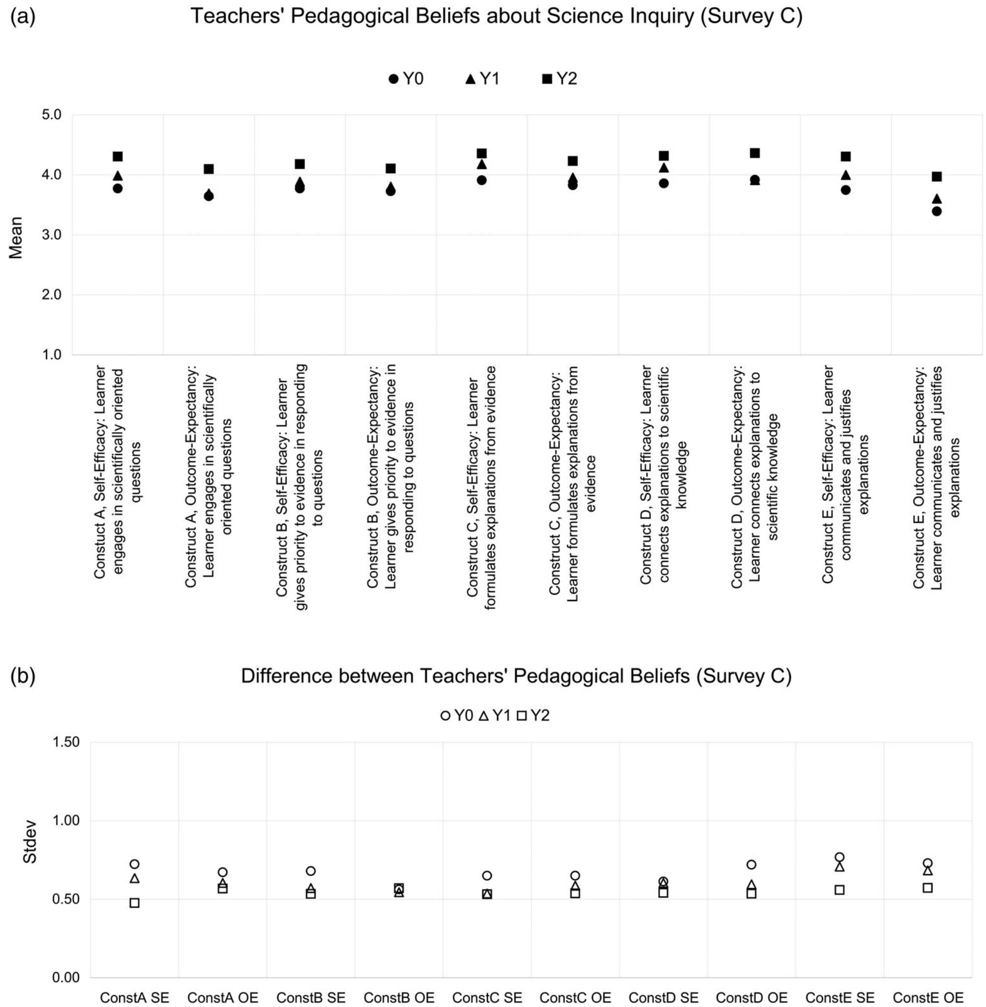

Figure 3. (a) Teachers' pedagogical beliefs about science inquiry over time (Survey C). (b) Difference between teachers on their pedagogical beliefs about science inquiry (Survey C).

Specifically, the difference between SE and OE was somewhat higher in Y1 (diff = 0.24) compared to Y0 (diff = 0.13) or Y2 (diff = 0.15), a larger effect size was found in Y1 (d = 1.12) than in Y0 (d = 0.58) or Y2 (d = 0.81), suggesting that the teachers may have had larger internal conflicts between their SE and OE in Y1 than Y0 or Y2. The teachers possibly began to increase their self-efficacy with science inquiry pedagogy as they gained additional knowledge and resources (i.e. curriculum modules) to enact it in their classrooms as part of their continued participation in TPD over time, yet still may have experienced problems with supporting students engagement in science inquiry pedagogy when returning to the classroom in Y1. This finding indicates that it may take more time for teachers to build trust in the outcomes of science inquiry pedagogy related to their students ability to successfully participate in it when compared to supporting teachers developing self-efficacy in science inquiry pedagogy.

Table 4. Correlations between years of TPD, teacher surveys, and students' CRT score means.

Measures		Teacher's technological skills (Survey A)	Teacher's ICT capabilities (Survey B)	Teacher's pedagogical beliefs (SE + OE) (Survey C)	Teacher's pedagogical beliefs: SE only (Survey C)	Teacher's pedagogical beliefs: OE only (Survey C)
Years of TPD	*r*	.553**	.440**	.321*	.321*	.309*
	Sig.	.000	.000	.001	.001	.001
	N	104	104	104	104	104
Students' achievement in science (CRT)	*r*	−.023	.242	.516*	.460*	.550**
	Sig.	.889	.132	.001	.003	.000
	N	40	40	40	40	40
Teachers' technological skills (Survey A)	*r*		.732**	.367**	.396**	.326*
	Sig.		.000	.000	.000	.001
	N		104	104	104	104
Teachers' ICT capabilities (Survey B)	*R*			.476**	.513**	.422**
	Sig.			.000	.000	.000
	N			104	104	104

*Correlation is significant at the .01 level (two-tailed).
**Correlation is significant at the .001 level (two-tailed).

Teacher learning and beliefs and student achievement

Our previous study (Longhurst et al., 2016) compared students' CRT scores between control groups (teachers that did not participate in TPD, $N = 30$) and intervention groups (teachers participated in TPD, $N = 23$), and showed that the students of teachers who participated in one year of professional learning significantly outperformed on the test compared to students of teachers who did not participate, $t\ (4524) = 3.94$, $p < .001$. Additionally, the students of teachers who participated in two years of professional learning significantly outperformed the students of teachers who participated in one year, $t\ (2095) = 2.55$, $p < .05$, or the students of teachers who did not participate, $t\ (4243) = 6.51$, $p < .001$.

To extend our previous research and to better understand the relations between teacher's professional learning and his/her students' achievement in science, we measured students' CRT means for individual teachers for each year and calculated Pearson's correlation coefficients between teacher survey results, year of professional learning, and their students' CRT score means. As can be seen in Table 4, there is a positive correlation between teachers' technological skills (Survey A) and the year of professional learning ($r = .553$, $n = 104$, $p < .001$), between teachers' ICT capabilities (Survey B) and the year of professional learning ($r = .440$, $n = 104$, $p < .001$), and between teachers' pedagogical beliefs about science inquiry (Survey C) and the year of professional learning ($r = .321$, $n = 104$, $p < .01$). Here, it should be noted that the teachers' pedagogical beliefs had a lower correlation than their technological skills or ICT capabilities to the year of professional learning. The results suggest that the teachers' pedagogical beliefs are resistant to change, and the change may come later than the learning of technology or ICT.

The correlation results between the teacher data and the students' CRT means (Table 4) show what we believe to be some of the most important findings of the study. Specifically, there was no correlation between the teachers' technological skills and the students' CRT means ($r = -.023$, $n = 40$, $p = .889$), nor between the teachers' ICT capabilities and the students' CRT means ($r = .242$, $n = 40$, $p = .132$). However, there was a positive correlation between the teachers' pedagogical beliefs about science inquiry pedagogy and the students' performance on the end-of-year science test ($r = .516$, $n = 40$, $p < .01$). While both teachers' SE and OE correlated to the students' CRT means, the students' CRT means had a somewhat higher correlation to teachers' OE ($r = .550$, $n = 40$, $p < .001$) than SE ($r = .460$, $n = 40$, $p < .01$), suggesting that the student achievement was more related to the teachers' outcome expectancy for the students than their self-efficacy.

Discussion

Teacher learning of technologies in longitudinal TPD

The teachers in the current study had significant gains of using technologies and ICTs in both years of participation in TPD, not only in the first year but also in the second year, and it suggests teachers' continuous growth of technological skills over the two years of TPD. Mehlinger (1997) reported that it requires at least 30 hours of training and experience to see the actual benefits of new technology. And, others argue that it may take several years for teachers to build expertise of using technology, especially when building the skill to integrate it in student-centered instruction (Hooper & Rieber, 1995; Sandholtz, Ringstaff, & Dwyer, 1997). The amount of time may vary depending on the complexity of the technology, grade, subject matter, teacher's skills and experiences, or pedagogy, among other factors. What seems clear from the literature and our study is that teachers' instruction may not change much if learning about technology is supported in only one-time event or short-duration PD. When professional learning takes place as longitudinal and continuous events, it offers teachers space to reflect on their use of technology in teaching (Blanchard et al., 2016), which can result in teachers' instructional changes with the use of technology.

What is notable, but often overlooked in TPD is that teachers have different experiences and abilities with technologies (e.g. Lee et al., 2012). Some teachers may have increased facility and confidence with technologies when compared to others (e.g. Lee et al., 2012). Therefore, their starting point at baseline (i.e. the beginning of TPD) may be very different. This was evident in this current research, as can be seen in the Figures 1(b) and 2(b) where the standard deviations between the teachers were large at Y0. However, after one year of intervention, the standard deviations or the gaps between the teachers' technological skills decreased. And, after two years the gaps became even smaller, as evidenced in decreasing standard deviations. Ultimately, while there remained noticable gaps in a few technological literacties and ICT capabilities (e.g. advanced skills using Microsoft Access), the standard deviations between teachers generally decreased as their time engaged in TPD increased. In other words, the longitudinal TPD enhanced individual teacher's confidence and facility in using technology, while also narrowing the differences between the teachers' technological skills.

Changes of pedagogical beliefs in longitudinal TPD

Unlike the technological literacies and ICT capabilities, the changes of teachers' pedagogical beliefs were not significant until after the second year, even though small positive, but not significant changes were seen in the first year. While it is difficult to say definitively what led to the significant increased beliefs about science inquiry pedagogy when these were not observed in the first year of TPD, one possible explanation can be found in considering what the teachers experienced in the two years of TPD. The teachers enacted modules 1 and 2 in Y1, then they enacted all modules, including the same modules 1 and 2, in Y2. Therefore, the teachers were already familiar with modules 1 and 2 when they enacted them in Y2. This familiarity in Y2 may have given the teachers confidence of using the technology, and gave them more space to better understand and enact student-centered science inquiry pedagogy. The teachers may have found the advantages of enacting scientific inquiry through multiple enactments, which could have subsequently shaped their pedagogical beliefs.

Plausible explanations for this observed change can be found within previous literature. According to Ertmer (2005), three types of experiences can affect teachers' pedagogical beliefs: *personal experiences*, *vicarious experiences*, and *social-cultural influences*. Related to personal experiences, Guskey (1986) reported that pedagogical beliefs change when teachers have successful personal experiences with new teaching practices. In the professional learning experiences of participants engaged in the current TPD being examined, personal experiences were afforded to participants as they engaged first as learners in technology-enhanced backward faded scaffolded inquiry-focused curriculum. Participants also had opportunities to implement the same curriculum in their own classrooms with their students. It seems that these *personal experiences* over a prolonged time (i.e. 2 years of engagment in TPD) helped support participants in negotiating the alignment between their beliefs and science inquiry pedagogy enhanced by technologies in ways that were found positively connected to student learning, but only after the second year of TPD.

Related to *vicarious experiences* and *social-cultural influences*, researchers have noted how observing others having successful experiences can motivate and influence changes in teachers' beliefs (Ertmer, 2005; Schunk, 2000; Zhao & Cziko, 2001) and how the *social-cultural influences* of participating in PD can influence teachers' beliefs as they interact with others in socially situated environments (Ertmer, 2005; Windschitl & Sahl, 2002; Zhao & Frank, 2003). Beyond the *personal experiences* of participants as learners and enacting project developed resources, *vicarious* and *social-cultural influences* are additional plausible influences on the teachers' beliefs over time in the longitudinal professional learning. In the current study, the teachers may have experienced positive benefits from *vicarious* and *social-cultural influences* as they observed and shared successful examples of project developed resource implementation with colleagues and engaged with one another over prolonged periods of time, which possibly influenced a change in their pedagogical beliefs.

Teacher learning and changes in longitudinal TPD and student achievement

Our study showed that the students' CRT score means were correlated to teachers' pedagogical beliefs, but not to their technological/ICT capabilities. This suggests that the more important factor impacting student learning is teachers' *pedagogical beliefs about how to teach with technology*, specifically related to science inquiry pedagogy, rather than their technological skills. This finding is aligned with previous research that technology should be used with the consideration of *how to integrate* it in instruction (Lei & Zhao, 2007; Li & Ma, 2010). As we described in the findings, pedagogical

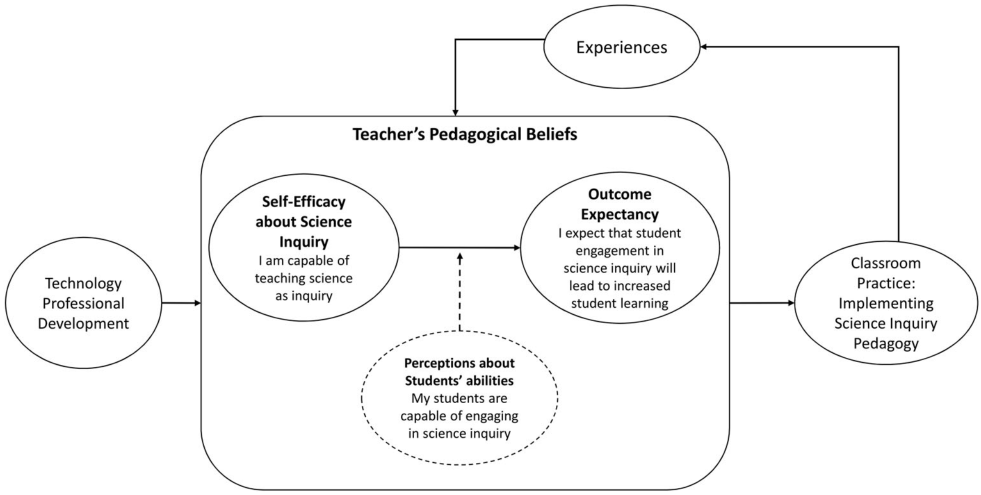

Figure 4. Teacher's pedagogical belief system.

change was not significant until after two years of TPD while technological skills significantly increased after one year of TPD. This points to the importance of longitudinal support for teachers as they make innovative changes in instruction by integrating technology into their classrooms in transformative ways. This is supported by Shymansky and his colleagues' study (2012) that students benefit more as their teachers participate longer in PD.

The significant differences between self-efficacy and expected outcomes of students in science inquiry pedagogy suggest that the teachers' perceptions about students' abilities may be relatively conservative. The teachers may not be confident about how their students might take up the new roles that are necessary as part of science inquiry pedagogy. Relatedly, in previous research, teachers had reported students' behaviours, attitudes, and abilities as one of barriers that they encountered when implementing technology-enhanced innovative pedagogy (Lee et al., 2012). It may also imply inconsistencies between the teachers' beliefs about their capabilities of facilitating science inquiry pedagogy and their actual teaching practices in class. These inconsistencies between teachers' beliefs and their actual abilities may be resolved as teachers participate in extended experiences implementing science inquiry pedagogy in their classrooms with students.

Figure 4 shows a proposed descriptive model hypothesised from what we observed in this current study related to how a teachers' pedagogical belief system affects their decision to implement science inquiry pedagogy. Once the teachers learn more about science inquiry pedagogy in TPD, they gain self-efficacy about the innovative pedagogy, which they better understand and have developing abilities to enact. But, as was seen in this research, the OE was lower in comparison to SE indicating that teachers may be hesitant or unsure of their students' abilities to take up the roles expected of them in science inquiry environments. However, when teachers have more experiences with students in classrooms alongside TPD, their expected outcomes of students related to science inquiry change over time. Additionally, this also possibly leads to changing teacher self-efficacy related to science inquiry pedagogy. However, additional research is needed to help gather additional evidences related to the validity of this hypothetical model.

Limitations of the study

The limitations of the study include the limited availablity of students' CRT scores for teachers during some years of the study due to state-level testing structure changes. Additionally, the teacher learning (i.e. technological literacy, ICT capabilities) and belief data (i.e. science inquiry pedagogy) were based on self-reporting surveys, without the benefit of a comprehensive classroom observation dataset that would allow for comparisions between these self-reporting surveys and teachers' actual classroom practice. We do not know if, in what ways, and how frequently, teachers used technology in their class. Therefore, the teachers' capabilities of technology and ICTs do not mean their actual use of technology in class. Instead, we know teachers' increased confidence about technology, assuming their increased technological skills.

Additionally, the researchers designed the TPD through close collaboration with district teacher leaders and did lead portions of the TPD; however, the teacher leaders also led TPD. Given this, there is at least a possibility that the double roles of the researchers as TPD leaders for a portion of the TPD could have influenced how participants completed the surveys. However, we cannot envision how the dual role could influence the student achievement data collected and analysed alongside the participant surveys. Because participants completed the initial surveys at the very beginning of TPD before having a chance to get to know the researchers, we also feel that the likelihood of the dual roles influencing participants' responses to the initial survey are greatly reduced. Therefore, the only real concern that should at least be mentioned is the possibility that engagement with researchers across the TPD could have influenced the participant surveys at the end of year 1 and again at the end of year 2. However, since we do not believe that early surveys were influenced and are confident that the dual roles did not play a role in student achievement outcomes, we believe this limitation is unlikely. In the end, even with these limitations, it is believed that this research still contributes significantly to the body of knowledge about TPD, since it reveals possible connections between teachers' reported learning, their beliefs, and student achievement and points to viable opportunities for future research.

Conclusion and implications

The current study suggests that the teachers became comfortable using the technologies and expressed increased ICT capabilities as they participated year-to-year in the two-year TPD. Specifically, the significant gains on the technological skills and ICT capabilities not only happened in the first year of TPD, it also happened in the second year of TPD. Unlike the technological skills and ICT capabilities, the teachers' pedagogical beliefs about science inqury were not found to be significantly different until after the second year of TPD. This implies that changes in pedagogical beliefs take more time than what is involved in learning about technologies. Most importantly, this research suggests a connection between student achievement in science and teachers' pedagogical beliefs, but failed to identify a similar connection between student achievement in science and teachers' learning about technologies. This suggests a more nuanced connection between the integration of technology in science instruction and the pedagogical beliefs and strategies that are necessary to make the technologies meaningful to student learning. While no data were available to further pursue this connection in this current research, it does point to the need and promise of this type of research in the future. In the end, while it remains unclear how the teachers' beliefs shaped their actual instruction in the classroom without classroom observation data to draw on, this research contributes meaningfully to the literature in TPD, especially related to teacher learning and beliefs in longitudianl TPD and the connection between teacher learning and student achievement.

Note

1. Two items were dropped from the original version of Markauskaite (2007), and one new item was added in this study to better align the survey with the specific technologies of the TPD.

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