Chapter 7
Professional Learning Using a Blended-Learning Approach with Elementary Teachers Who Teach Science: An Exploration of Processes and Outcomes

Xavier Fazio and Kamini Jaipal-Jamani

7.1 Introduction

Professional development programs (PDPs) are purposeful learning experiences that require tremendous resources from schools and districts. One important priority for science education is to improve the pedagogical knowledge and skills of practicing science teachers through PDPs. An evolving understanding of how best to teach science calls for a significant transition in the way science is currently taught in classrooms and will require many science teachers to innovate how they currently teach science (Darling-Hammond et al., 2017; Luft & Hewson, 2014; National Academies of Sciences, Engineering, & Medicine [NASEM], 2015). One way for science teachers to develop their professional practice is through a twenty-first century learning approach using a blended (i.e., online and face-to-face) program. While not new (e.g., Boitshwarelo, 2009; Hotze et al., 2020; Owston et al., 2008; Psillos, 2017), this model has never been researched as part of a large-scale PDP implemented by a teaching association in Canada. Blended PDP has been initiated by other teacher professional associations (e.g., National Science Teaching Association, 2020), but results from such studies may not be fully applicable across contexts. Conducting research that is specific to teaching communities and diverse populations is also important and necessary for Canadian educators to improve classroom teaching practices (Campbell, 2017).

X. Fazio (✉) · K. Jaipal-Jamani
Faculty of Education, Department of Educational Studies, Brock University, St. Catharines, ON, Canada
e-mail: xfazio@brocku.ca

K. Jaipal-Jamani
e-mail: kjaipaljamani@brocku.ca

C. D. Tippett and T. M. Milford (eds.), *Exploring Elementary Science Teaching and Learning in Canada*, Contemporary Trends and Issues in Science Education 53,
https://doi.org/10.1007/978-3-031-23936-6_7

Our evaluative research focused on a PDP, herein referred to as 'Science Teaching Innovation' (STI); its three main elements were implemented in chronological order: face-to-face presentations and workshops, collaboration and coaching via an online learning platform, and knowledge mobilization through resource sharing of grade-specific curriculum artifacts. STI's program focus was consistent with science curriculum reform initiatives including Canadian and USA standards documents (e.g., British Columbia Ministry of Education, 2019; Luft & Hewson, 2014; National Research Council, 2013; Ontario Ministry of Education, 2008, 2022), which foreground student sense-making and the emergence of science concepts from classroom practices and events that support knowledge development with students in schools (Sandoval, 2015; Thompson et al., 2016). This study addressed the importance of teacher professional learning in Canada and supports recommendations regarding the readiness of Canada's teachers and students to meet future skill requirements in science, technology, engineering, and mathematics (STEM; Council of Canadian Academies, 2015).

While the STI program involved K–12 science teachers, the focus of this chapter is to highlight research results evaluating its impact on elementary science teachers. Based on analyses of these results, recommendations will be provided regarding design principles for blended-learning PDPs appropriate for PK–12 educators. Furthermore, this study addresses the importance of future research regarding science teacher professional learning in Canada.

7.2 Background and Conceptual Framework

The research on teacher PDPs is extensive; over the last two decades, researchers have reached a consensus on key features of highly effective, in-person programs. Key PDP features are situated in classroom practice, focused on student learning, embedded within professional learning communities, and sustained over time (Bybee & Loucks-Horsley, 2000; Guskey & Yoon, 2009; Hill et al., 2013). Other features of effective PDPs include active learning workshops based on research-based practices, teacher study groups, and discipline-specific content and pedagogy (Darling-Hammond et al., 2017; NASEM, 2015; Penuel et al., 2007). Furthermore, Windschitl (2009) maintained that the above features—together with the collaborative participation of science teachers in the same school, grade, or subject areas—support students' development of twenty-first century competencies.

Despite a consensus in the literature on PDPs, there is limited evidence of the specific characteristics of PDPs that use a blended-learning approach (Community for Advancing Discovery Research in Education [CADRE], 2017; NASEM, 2015; Wayne et al., 2008). Indeed, little research is available on how to develop science teaching and technology integration effectively within a blended-learning approach (NASEM, 2015). The limited research findings do suggest that there is promise in using a blended-learning strategy for PDP design in science and mathematics (Hodges et al., 2013; Owston et al., 2008; Sinclair & Owston, 2006). Research also suggests that PDPs are enhanced by a network of communication between facilitators and teachers, along with face-to-face connections amongst the teachers themselves (Luft & Hewson, 2014; NASEM, 2015). For this chapter, we will briefly describe the practices promoted through STI's blended framework: scientific inquiry and technological design, technology-mediated pedagogies, critical thinking, and other twenty-first century skills.

7.2.1 Scientific Inquiry and Technological Design

Scientific inquiry and technological design pedagogies are generally defined as approaches that provide students with opportunities to engage and understand scientific and engineering practices regarding natural or human-designed phenomena (e.g., Alberta Education, 2014; NRC, 2013). These approaches are typically experiential in nature and can be organized into recognizable pedagogical models such as inquiry-, problem-, design-, and project-based learning approaches. Often the teacher and students work collaboratively with respect to the amount of guidance, personalization, and performance features required when implemented in science classrooms. Further, these models are oriented toward meaningful understanding of scientific or engineering concepts along with developing expertise in students' planning, performance, and communication competencies for future application in diverse school and community contexts (Organization for Co-operation and Development [OECD], 2017; Peterson et al., 2018).

7.2.2 Technology-Mediated Pedagogies

Technology-mediated pedagogies are broad, learner-centred approaches that use information and communication technologies (ICT). These technologies have become pervasive in our schools and society (People for Education, 2019). In a science classroom, for example, this may include the use of tablets, laptops, desktops, smartphones, projectors, video conferencing apparatus, 3-D printers, robots, and probeware sensors. Connecting these devices to local and cloud-based software for students to individually or to collaboratively access online information and multimedia has become reasonably common practice in schools. Importantly, the use of technology-mediated pedagogies to enhance, rather than distract, students' science learning has become an important goal for science teachers (Krajcik & Mun, 2014). In addition, these technology-mediated pedagogies connect to both didactic and experiential pedagogies. For example, independently learning science content by viewing a lecture on video scaffolded with a series of structured questions is a common online didactic pedagogy; team collaboration on an online discussion platform to engage in problem- or project-based learning is a common experiential pedagogy (Bates, 2018).

7.2.3 Critical Thinking

Critical thinking in education is a popular program goal that involves cognitive processes that pedagogies help to promote. According to Hitchcock (2018), it is more useful to describe characteristics of critical thinking rather than try to come up with a succinct definition. In general, critical thinking has the following features:

- It is a goal-oriented process for the purpose of deciding upon future actions or views.
- The student engaging in the thinking is trying to fulfill standards of accuracy appropriate to the thinking of the discipline in relation to scientific propositions or claims.

Often critical thinking is conflated with Bloom's evaluating thinking category; however, it necessitates metacognitive thinking (Ennis, 2016). Students in science might employ critical thinking processes by inferring, experimenting, observing, hypothesizing, researching, and evaluating scientific phenomena and claims.

7.2.4 Other 21st Century Skills

The United States NRC (2013) has categorized twenty-first century skills into three areas of competency—cognitive (e.g., critical thinking skills), intrapersonal (e.g., metacognition skills), and interpersonal (e.g., communication)—and recommends a deeper learning approach to develop these competencies. Deeper learning or meaningful learning is described as the process through which an individual becomes capable of taking what was learned and applying it to new situations (i.e., transfer) (NRC, 2013). A mutual, reinforcing relationship exists between deeper learning and twenty-first century competencies. The NRC further recommends the use of pedagogical strategies such as modeling, guided inquiry, and technology-mediated activities to engage in deeper learning to develop these skills. The PDP in this study was informed by the need to provide teachers with knowledge of, and practice with, inquiry and engineering design practices along with technology-enhanced strategies to support deeper learning in school science.

7.2.5 STI Professional Development Program Features

An operational model of how PDPs can impact teachers was proposed by Desimone (2009). In this model, teachers participate in programs that in turn increase their knowledge and skills or change their views on science instruction. From this, teachers adapt their instructional practices and subsequently can impact student outcomes. Of importance to these efforts is the sequence in which these events occur (Guskey,

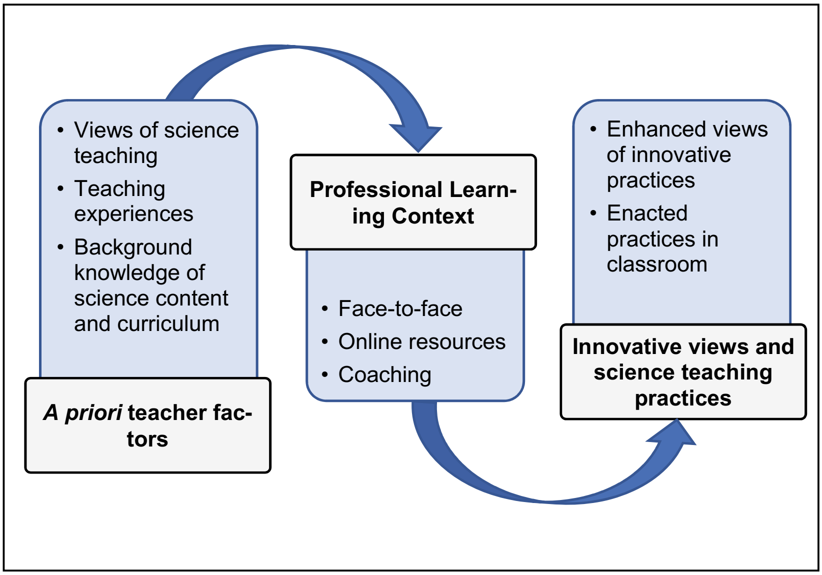

Fig. 7.1 Framework for the STI professional development program

2002). While this model does not take into consideration all the complexities of delivering PDPs, such as school contexts (e.g., Fazio, 2009; Sandholtz & Ringstaff, 2016), the STI program was primarily designed using this model (Fig. 7.1). We agree with Desimone's proclamation that this model is still worthy of careful investigation as it would elevate the quality of PDP studies, particularly in Canada, where there is a scarcity of such research.

Noteworthy for this study was how the STI program promoted innovative science teaching using a blended approach that included face-to-face interactions, online communication, and support though the teaching association's model of online coaching. Nevertheless, blended PDPs can vary considerably; and evidence is still sparse on its impact on science teacher practices (NASEM, 2015; Wilson, 2013). For this study, blended learning was demonstrated as an application of content ideas online with coaches (i.e., facilitators) after face-to-face interactions with teachers at an annual professional conference and prior to their pedagogical sharing at the next annual conference.

7.3 Methodology

The objectives of this research were to (a) evaluate the impact of the PDP on participating science teachers' views and practices and (b) provide recommendations for future professional learning opportunities for inservice science teachers. Thus, the focus of this research project was evaluation research versus basic or applied research. In general, the goal of evaluation research is to make judgments on specific programs and provide recommendations for program providers or external agencies (McMillan, 2004). In this study, our research roles were circumscribed as long-standing and trusted colleagues with the science teaching association delivering the STI program; yet we maintained a professional distance from the PDP's design and implementation. Finally, this study was reviewed and approved by a university ethics review board.

The study utilized a mixed-methods approach employing a concurrent design with qualitative and quantitative data, separate data analysis, and integration of the two data types (Creswell, 2012; Teddlie & Tashakkori, 2009). The research objectives were to:

- Assess changes in the elementary teachers' science educational views (efficacy, instruction) and practices (inquiry, technology-enhanced, critical thinking) based on their participation in the PDP
- Identify strategies and practices enhancing the effectiveness of blended professional development based on the research findings.

Over the two years of data collection (2015–2017), there were 142 elementary teacher participants (Year 1 = 59; Year 2 = 83) with four cohorts of approximately 20–30 participants per year organized in grade groupings: Kindergarten to Grade 3 (primary), Grades 4 to 6 (junior), Grades 7 and 8 (intermediate). The participants were elementary teachers from across the province who took part voluntarily although some participants were selected to attend based on centralized school district decisions. Note that grades up to Grade 8 are typically considered part of the elementary panel in the province. Note that we do not identify the province in order to maintain our anonymity requirements for this study.

7.3.1 Timeline, Data Sources, and Analysis

A timeline of the project and delineation of the research activities undertaken for the study are shown in Fig. 7.2. The study was undertaken in the 2015–2016 and 2016–2017 academic years involving two different groups of science teachers. Data sources for the study included online surveys using SurveyMonkey™ prior to the implementation of the program and after completion of the online phase. In addition, there were written evaluations of workshops at the face-to-face program, analysis of discussions posted on STI's online learning platform, interviews with teacher participants representing all the cohorts noted earlier during the online phase of the PDP, document analysis of teacher-developed classroom resources, post-program surveys, and interviews with select teachers at the sharing sessions. Due to page restrictions for this chapter, we cannot present a full representation from the data corpus. Summaries are provided with respect to the data sources and results. The

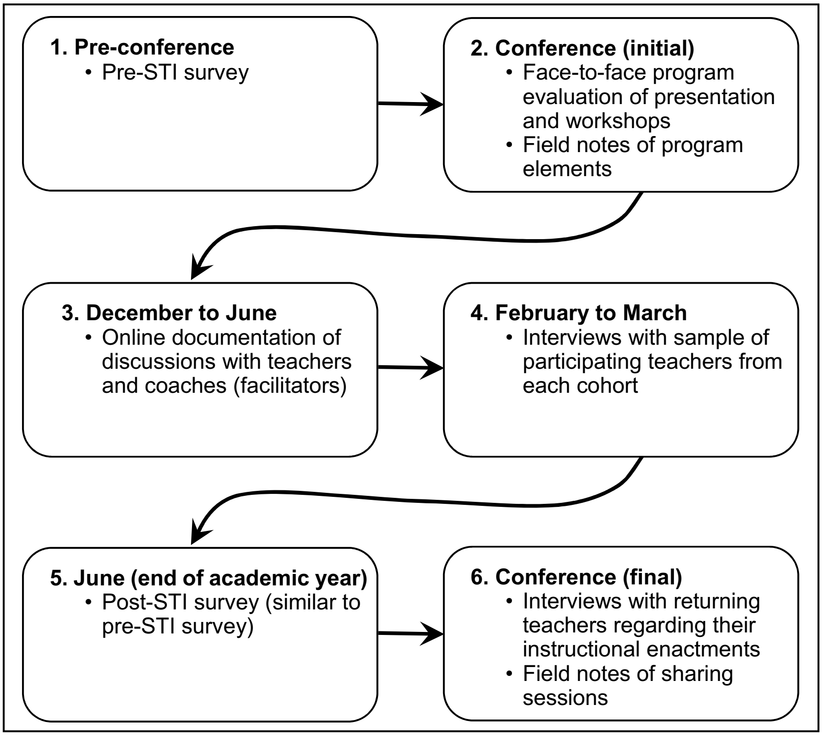

Fig. 7.2 STI program features and summary of data collection activities for a one-year cycle

question themes used for the various data collection activities identified are provided in Table 7.1.

All qualitative data sources (e.g., interviews, online discussions, open-ended questions from pre/post surveys) were transcribed. Text analysis involved coding and categorization of recurring themes using a multistage and iterative procedure guided by the processes of exploring and describing the interpreted qualitative data (Creswell, 2012; Merriam, 2009), facilitated by NVivo™ software.

The quantitative data sources (e.g., pre/post surveys) were analyzed using IBM SPSS Statistics. Quantitative analyses involved descriptive, parametric, and non-parametric statistics appropriate to the data sets produced from the pre/post program surveys. Descriptive statistics were produced for each quantitative-based survey question. This included frequency and percentage distributions for all items on Likert-type scales or rank-order questions. The descriptive statistics included mean, standard deviation, and composite scores where applicable. To address the research objectives, the primary focus of the inferential statistical analyses was on group comparisons before and after the STI program, that is, pre/post program comparisons. Unless noted, the data comparisons were overall comparisons of the entire program (i.e., Years 1 and 2 data combined). Owing to sample-size considerations, comparisons

Table 7.1 Data collection instruments and questions themes

Data collection instruments	Question themes
STI surveys (44 questions) Likert-type Rank ordering Open-ended questions	Demographic Past professional development experiences in science Science Teaching Efficacy Belief Instrument (STEBI- Elementary) Type and frequency of various of forms of instruction and assessment Confidence with and frequency of using scientific inquiry, technological (engineering) design teaching Confidence with and frequency of using technological tools for instruction Confidence with and frequency of teaching critical thinking Instructional resources used Obstacles to teaching science
Face-to-face evaluation of workshops (initial conference)	Relevance of topic to instruction Impact on knowledge of topics (e.g., inquiry, technology enhanced instruction) Quality of workshop Clarity of STI PDP aims and next steps
Interviews with sample teachers (midpoint)	Demographics and professional qualifications Past professional development experiences in science Views of and frequency with scientific inquiry/technology design teaching, technological-enhanced instruction, critical thinking instruction Current views of the STI PDP and progress to date Use of the online platform for professional learning Challenges of STI PDP and new understandings
Interviews (final conference)	Review of instructional activities/unit (enactments) implemented in their classroom Identification of any new learnings based on their instructional enactments Benefits and challenges of STI PDP

among smaller cohorts (e.g., Kindergarten–Grade 3 vs. Grades 4–6 cohorts) were not deemed statistically sufficient.

A limitation of the study was that data were not collected in school settings due to restrictions in our research roles based on the scope of the evaluation project. Other limitations include self-reporting bias in the surveys, and the potential for participant bias based on the convenience sample for the interviews based on researcher selection, which may have been further impacted because of the attrition of participants in some cohorts. Nevertheless, since data were collected across multiple cohorts over two academic school years, more robust conclusions can be drawn about the effectiveness of a blended PDP. Additionally, there was high confidence in our capability to address the research objectives.

7.4 Results

As identified earlier, a concurrent mixed-methods research design was used for this research study. We highlight our analyses appropriate to the themes presented in this section. The results provided are exemplars only due to page restrictions. Our analyses of data were collected from participants in either Years 1 or 2 of the STI program—different groups of elementary teachers. Our results consist of examples that includes participants' responses from an evaluation questionnaire of the face-to-face program sessions, interviews with convenience-selected participants (selected in a randomized manner and contacted for availability) from various cohorts, interviews with participants presenting at the "Sharing the Learning Showcase" in Fall 2016 and 2017, responses to open-ended questions on the survey administered to participants at the end of the PDP, participants' engagement data on the STI online platform, and pre- and post-STI survey data. The findings below are supported with exemplars and are organized according to the thematic categories from our analysis: changes in pedagogical views and practices, teaching self-efficacy changes, active learning, and motivating and sustaining engagement online.

7.4.1 Changes in Pedagogical Views and Practices

Based on analyses of both quantitative and qualitative data, the STI program had modest impact on these teachers' views with respect to innovative teaching practices. More specifically, fine-grained analyses of pre/post program survey data comparisons (see Fig. 7.3 for results and survey questions) illustrate that these elementary teachers improved their views significantly with respect to their teaching effectiveness of inquiry- or design-based science teaching and certain technology-enhanced teaching to address the science curriculum. What we mean by significance is that there is a 5% probability that the results are due to chance alone. For survey question about the teachers views (i.e., agreement with) about various innovative instructional practices (Fig. 7.3), the Mann–Whitney U test statistic was $M = 3.98$ (pre), $M = 4.32$ (post) $U = 1885$, $z = -2.325$, $p = 0.02$ for their views about using inquiry or design teaching to address the Ontario curriculum, and teaching with technology to address the Ontario curriculum was $M = 3.78$ (pre), $M = 4.11$ (post) $U = 1887$, $z = -2.366$, $p = 0.018$. We consider these as significant increases, $p < 0.05$. However, they did not improve significantly pre/post program with respect to their views of inquiry and technology pedagogies to develop students' critical thinking skills or understanding

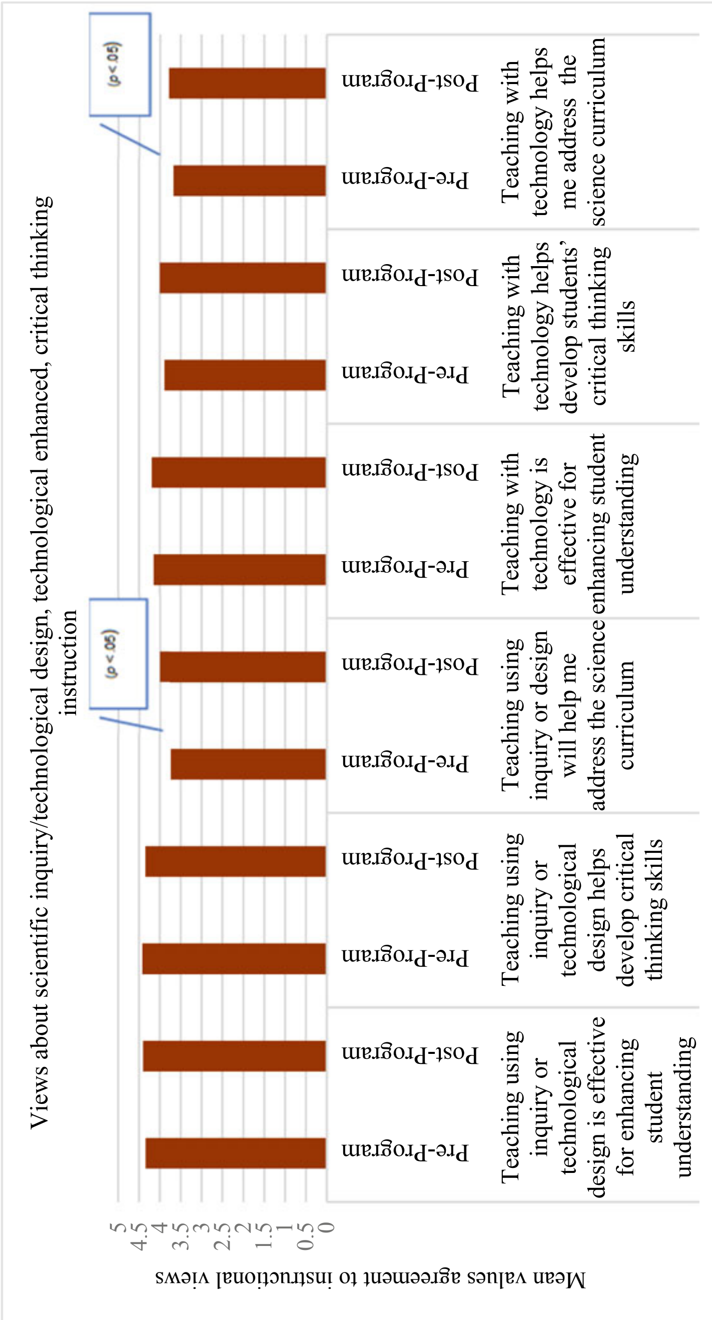

Fig. 7.3 Mean values for elementary teachers' instructional views pre/post STI program about scientific inquiry/design and technology instruction to address curriculum and critical thinking

in science. While there were positive trends in other instructional views pre/post STI program, statistical comparisons found no significance.

Elementary teachers were asked, “How often do you incorporate various inquiry-based instructional strategies into your science instruction?” These strategies included using deductive and inductive approaches, developing students’ questions, having students make claims using evidence, and communicating their results. While elementary teachers in both years reported a positive trend in frequency of use of inquiry-based strategies in their respective classrooms, overall, there was no statistically significant differences pre/post STI program for both Years 1 and 2 groups with respect to inquiry elements. However, there was one exception: reported frequency of allowing students to develop their own questions.

It is clear that these elementary teachers’ instructional views improved regarding using inquiry and engineering design as well as teaching with technology to address the science curriculum. While there was a positive trend for views of technology-enhanced learning practices in their respective classrooms, there was no significant difference reported in frequency of technology use post-STI program. These findings were partially corroborated with data from interviews where teachers highlighted changes in their innovative instructional views and practices due to the STI program.

> It is a great program [STI] that compelled and motivated me to adapt and evolve my teaching to empower learners with the skills needed for future (Junior teacher, sharing showcase).
>
> It helped me better understand what inquiry is and what it might look like in the science classroom (Intermediate teacher, sharing showcase).
>
> It inspired me to be more hands-on and innovative (Intermediate teacher, sharing showcase).

However, comments after the face-to-face workshops portrayed a mixed picture of the impact of the initial component of the PDP.

> I would have liked to have seen more examples of how to incorporate technology and inquiry into my classroom (Primary teacher, face-to-face evaluation questionnaire).
>
> Lecture style is not valuable. You should emulate what you want students to do! For science, explore and wonder first and then come back and consolidate over the learning together like you would in a classroom. PDP should follow this model (Intermediate teacher, face-to-face evaluation questionnaire).
>
> More hands-on activities and less ‘theory’ presentations (Junior teacher, face-to-face evaluation questionnaire).

Of interest were findings that elementary teachers demonstrated significant decrease, $M = 2.37$ (pre), $M = 2.09$ (post) $U = 7035$, $z = -2.998$, p 0.04, when comparing pre/post program surveys regarding their frequency of use of teacher-directed and surface-level instructional practices (e.g., teacher explaining science concepts, memorizing science vocabulary). This evidence highlights the beginning of a shift in instructional classroom practices (Guskey, 2002). Nevertheless, significant shifts in instructional competencies related to the innovative pedagogical foci (i.e., inquiry, technology enhanced, critical thinking) due to the STI program were not found in the survey data.

7.4.2 Teaching Self-Efficacy Changes

The online survey had one set of Likert-type statements that measured participants' self-efficacy based on the Science Teacher Efficacy Belief Instrument (STEBI; Riggs & Enochs, 1990). A subset of these statements yields scores for the Personal Science Teaching Efficacy (PSTE) subscale, which reflects science teachers' confidence in their ability to teach science. The other subset yields scores for the Science Teaching Outcome Expectancy (OE) subscale, which reflects science teachers' beliefs that student learning can be influenced by effective science teaching. Data from the STEBI subset of survey questions uncovered that Year 1 elementary teachers' science teaching efficacy scores increased significantly, paired samples t-test $M = 3.8692$ (pre), $M = 4.2708$ (post), $p < 0.01$. However, the Year 2 elementary teachers efficacy scores did not change significantly even though there were efforts made by the teaching association to improve the STI program in terms of differentiating the face-to-face component of the PDP for the participating teachers.

7.4.3 Active Learning

Face-to-face sessions provided pragmatic pedagogical strategies for designing inquiry and engineering design-based curriculum units, which spurred changes in teaching practices for some teachers. An intermediate science teacher from the sharing sessions described how ideas gained from workshops at the beginning of the program influenced their views about innovative science teaching and their corresponding practices:

> I would not have done this [classroom engineering project] without the STI program. A workshop speaker showed us how inquiry and engineering practices looked and how you stage it, so you do it step-by-step. Whereas in our schools we have always been told to do inquiry and you are kind of left to do your own inquiry … it was an eye opener. [Intermediate teacher, key participant interview]

The knowledge initially gained from the face-to-face sessions enabled these teachers to modify their teaching practices prompted by active learning experiences so that they could in turn engage their students in self-directed inquiry and engineering-based learning. The evidence of student engagement in inquiry and design-based learning was showcased at the end of the PDP, where participants shared the inquiry/design or technology-enhanced student learning activities or projects they implemented within their respective classrooms. Figure 7.4 shows how a teacher participant engaged students to solve the problem of creating a launch pad that would allow rockets to go the furthest distance. The knowledge she gained from the STI program enabled changes to her teaching practices so that she was able to engage her students in self-directed inquiry—something she had not done before. As the teacher explained, "Previously, I felt that I had to direct them because they wouldn't learn if

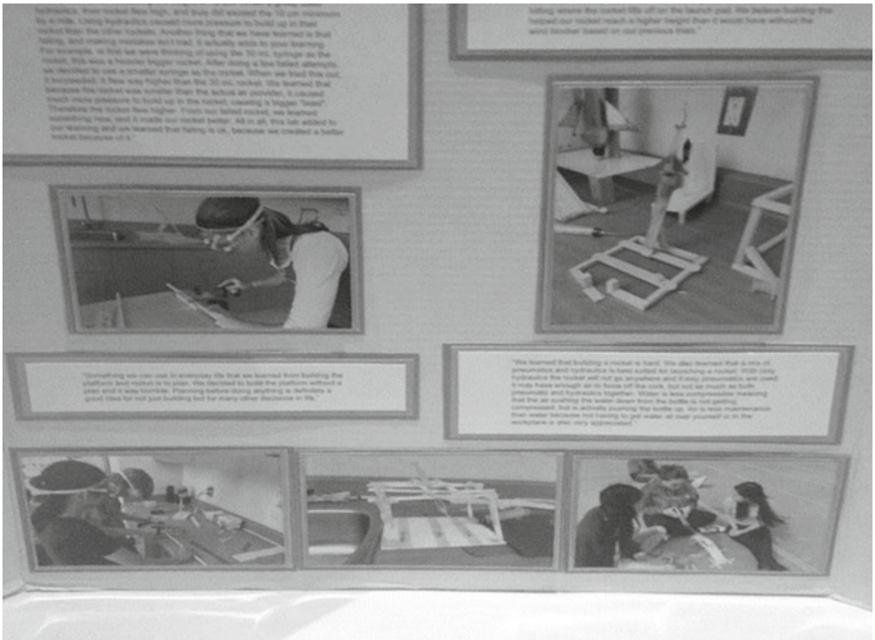

Fig. 7.4 Poster presentation from an elementary teacher showcasing student inquiry and design projects

I didn't." These findings showcase the importance of active learning and its impact on pedagogical change for teachers (Darling-Hammond et al., 2017).

7.4.4 Motivating and Sustaining Engagement Online

Prior to the elementary teachers' participation in STI, they were surveyed about their experiences with professional learning in an online environment. Only one-third said they would consider learning online, and one-half said that they would not consider this form of learning. The online PDP platform was an important and novel professional learning feature for the STI program. Supporting the online activity were designated online mentors who were experienced science teachers. These individuals were responsible for facilitating cohort discussion (i.e., Grades K–3, 4–6, 7–8) and supporting online teacher learning after the face-to-face participation until the end of the academic year. By the end of the program, participation with the STI online activities seemed to improve only marginally, as shared by one participant in an interview.

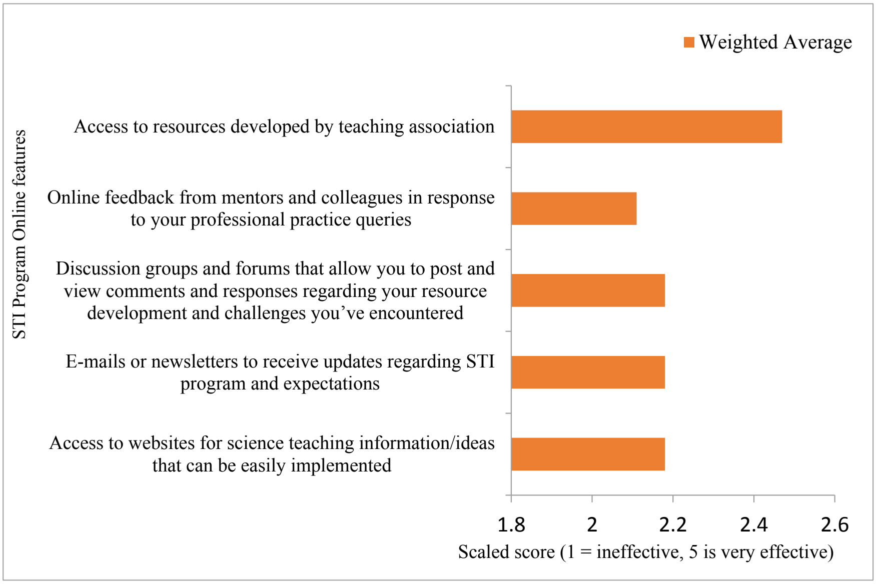

Fig. 7.5 Effectiveness of the STI program online features for improving professional practices

> I've been on it [online platform]. I found it very frustrating to be honest with you. Was it the technical? the structure? I can't put my finger on it. I've been on it and I just did not find it enjoyable, the interface. I think that's it. It's the interface that threw me off. I think if it were simpler then I would use it more. (Junior teacher, key participant interview)

This quote expressed the uncertainty and frustrations that many of the participating teachers experienced with the online features of the STI program. The survey results (Fig. 7.5) further illustrate the challenges inherent in various online features of the program.

7.5 Discussion

The STI professional learning program identified innovative teaching practices relevant to many twenty-first century teaching priorities for science education (i.e., inquiry-based, technology-enhanced, critical thinking). Based on analyses of both quantitative and qualitative data, the teaching association's PDP program had modest impact on elementary teachers' views and associated instructional practices. Elementary teachers participating in the project improved more than their secondary science teacher counterparts (not included in this chapter's review). Specifically, modest changes toward more progressive views of inquiry-based science and technology-enhanced instructional views were evident with these elementary teachers by the end of the STI program. The same cannot be said for teaching critical thinking, where little evidence of changes for this professional learning goal was found in the teachers' views or practices data.

Inferring from the survey data, there were more improvements with elementary teachers in Year 1 than the subsequent Year 2 group, as detected by their teaching efficacy scores. Still, based on the aggregated data collected through the surveys and interviews across both years of the STI program, significant shifts in either group's science teaching efficacy were not found. Corroborating these findings with participant interviews highlights an important research finding from this study: improving general science teaching efficacy may not be a sufficient condition toward adopting innovative science teaching practices.

Another interesting finding is that these elementary teachers demonstrated statistically significant decreases in teacher-directed and surface-level instructional practices (e.g., teacher explaining science concepts, memorizing science vocabulary). In addition, the teachers began to show confidence (as measured through the pre/post surveys) in dealing with obstacles to teaching science (e.g., inadequate materials/equipment). This evidence highlights the beginning of a shift in instructional classroom practices and is an important external marker documenting professional learning (Guskey & Yoon, 2009). Nevertheless, significant shifts in instructional competencies related to the innovative pedagogical foci (i.e., inquiry, technology-enhanced, critical thinking) of the STI program were not found in the data collected.

From an individual case versus aggregated perspective, some individual elementary teachers benefitted from their participation in the STI program and modified their practices. These teachers showcased their innovative pedagogical practices and curriculum development experiences at the sharing sessions at the end of the program. After interviewing some of these teachers, many can be described as motivated and willing to embark on new learning when presented with a professional learning opportunity. This finding aligns with current research on teacher competencies and innovative teaching where professional learning, cooperation, ethical, and communicative competencies are highly correlated with professional learning and the implementation of innovative teaching practices (Zhu & Wang, 2014). Furthermore, some of these motivated individuals were already part of similar professional learning initiatives in their respective school or district prior to their participation in the STI program. These observations speak to the importance of differentiating professional learning for teachers when they voluntarily participate in PDPs (Grierson & Gallagher, 2009).

The opportunity for science teachers to explore and engage in active, in-person learning activities (e.g., doing inquiry or practice using digital technologies) designed for their students was clearly relevant to the participants. Nonetheless, interviews and survey results highlighted that even modest improvements in general science teaching efficacy may not be sufficient for adopting these specific innovative teaching practices. This finding resonates with other PDP research and the impact of teachers' respective school cultural and political contexts (Fazio & Gallagher, 2018; Penuel et al., 2007).

One challenge observed in the STI program was sustaining teacher engagement after the face-to-face components were completed. Indeed, the attrition rate for the teachers who either did not complete the final program elements or participate in the final survey was approximately 30%. A possible explanation could be that when teachers were challenged with implementing innovative teaching practices, the cognitively and emotionally demanding experiences made it more difficult to sustain engagement, especially when the PDP had an online requirement. This explanation has been found with other blended PDPs (e.g., CADRE, 2017; Hodges et al., 2013). Furthermore, technological demands for online learning (e.g., using web-based platform and online communication tools) exacerbated this situation. Indeed, the participants who struggled yet sustained their engagement with the STI program commented in interviews regarding this specific challenge.

> The STI project connected teachers from different schools in the same area but, because there was no release time for us to connect together, it fell apart. So, then I had to make my own group at school [with teachers not part of STI]. (Intermediate teacher, key interview participant)

> I think that if I had a partner at my school the program would have been more successful for me. (Junior teacher, key interview participant)

The literature reports that a structured yet flexible online learning environment provides a better engagement platform than an overly flexible and less-defined experience (Owston et al., 2008), which was evident with the STI program.

Critical to any successful PDP is the transfer and implementation of teachers' learning into their school context. An organizing framework is required to help elementary science teachers with this process. While outside the chapter focus, promising work with respect to using a collaborative inquiry research approach (i.e., collaborative action research or design-based research) is a promising strategy for professional learning that science educators can use to adapt existing practices and adopt innovative teaching approaches aligned with curricular and pedagogical reforms and that are relevant to their school context (Fazio, 2009; Fazio & Gallagher, 2019; Goodnough, 2018; Maeng et al., 2020).

7.6 Implications and Recommendations

Designers of PDPs face many decisions when planning professional learning, yet there may be little evidence from the research corpus to support these various decisions (Hill et al., 2013). Our findings provide specific recommendations and contribute to the research call aimed to identify evidence-based practices from large-scale studies in blended-learning PDPs for K–12 science teachers (Polly & Hannafin, 2010). Furthermore, this study investigated research conjectures for teacher change and instruction, which are necessary to contribute to our understanding of how PDPs work, especially in blended-learning environments (Desimone, 2009; Wayne et al., 2008).

Based on our study, and supported by existing literature, we identified seven specific recommendations for blended PDPs to improve science teacher engagement in the STI project. Some recommendations may be applicable to other professional development projects with study designs similar to that used in the STI project. We recommend the following strategies:

- Provide technological supports to practice with online applications required for collaborating.
- Create mutual accountability structures, such as division of group tasks and timelines amongst participants, to maximize productivity and encourage online collaboration.
- Integrate face-to-face synchronous and asynchronous meetings during the online component.
- Plan online events that use learning objects to focus pedagogical discussions and subject-specific practices.
- Utilize online tasks that encourage reflection surrounding a curriculum product and student work.
- Modify the professional development expectations based on the social-cultural perspectives of the schools and districts where the teachers are working.
- Provide more initial face-to-face workshops that involve hand-on experiences with topics (e.g., engineering design) and technology-enhanced pedagogy that increase the confidence and capabilities of the teachers prior to embarking on online PDP experiences.

The science teaching association providing the PDP is dedicated to improving the teaching of science and providing professional learning opportunities and resources for science educators. To that end, the STI design team embarked on an ambitious journey of professional learning for science teachers. Acknowledging teachers' preservice and inservice science experiences, adapting to school contexts and provincial ministry of education policies, and honouring professional motivations and classroom experiences is difficult to accomplish. Recognizing that teacher learning is a complex endeavour is an important consideration for future professional learning programs. To be effective, adequate time must be provided for science teachers to learn, practice, and implement innovative teaching strategies (Darling-Hammond et al., 2017; Mutch-Jones et al., 2022).

As a professional learning opportunity, the STI program provided a catalyst for motivated science teachers to further their knowledge regarding innovative pedagogies. However, many of the participating science teachers were unable to sustain their engagement with the PDP, particularly after the face-to-face component was completed. While the STI online platform was a novel and potentially useful learning platform for teachers, specific online and other accountability practices (e.g., required online meetings, periodic face-to-face sessions) are essential to effectively use this digital twenty-first century learning approach. Almost certainly, future designs that use a blended-learning approach must take into consideration effective design features (e.g., flexible yet accountable online requirements, sharing of curricular exemplars online, frequent feedback on pedagogical practices) that have worked successfully in other intensive online PDPs (CADRE, 2017; Fernandes et al., 2020; Owston et al., 2008).

Attention to the integrated recommendations from the participants and extant research literature (e.g., NASEM, 2015) is essential for future PDP providers who may wish to develop programs for science teachers. Indeed, some of the successful and unsuccessful design elements have been already tested by many existing programs in Canada and abroad (Campbell, 2017). Substantially less research exists on opportunities for professional science teacher communities in schools, mentoring and coaching, online learning, and science teacher networks (NASEM, 2015). This research project sheds light on the nebulous area of professional learning for science teachers, especially relevant in Canada where very few studies exist. With a shifting educational policy agenda in Canada and abroad, professional learning for science educators must be redesigned to meet science students' needs. We see this study as the beginning of an important trajectory for the science education community. Only through a system of collaboration with practicing science teachers—along with evidence-informed feedback from researchers and PDP providers—will there be professional learning that supports comprehensive adoption of innovative science teaching practices in Canadian schools.

References

Alberta Education. (2014). *Science grades 7–8–9: Program of studies.* https://education.alberta.ca/media/3069389/pos_science_7_9.pdf

Bates, A. T. (2018). *Teaching in a digital age: Guidelines for designing teaching and learning* (2nd ed.). Creative Commons Attribution NonCommercial.

Boitshwarelo, B. (2009). Exploring blended learning for science teacher professional development in an African context. *The International Review of Research in Open & Distributed Learning*, *10*(4). https://doi.org/10.19173/irrodl.v10i4.687

British Columbia Ministry of Education. (2019). *BC science curriculum.* https://curriculum.gov.bc.ca/curriculum/science

Bybee, R. W., & Loucks-Horsley, S. (2000). Advancing technology education: The role of professional development. *The Technology Teacher, 60*, 31–34. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.680.5344&rep=rep1&type=pdf

Campbell, C. (2017). Developing teachers' professional learning: Canadian evidence and experiences in a world of educational improvement. *Canadian Journal of Education*, *40*(2), 1–33. https://journals.sfu.ca/cje/index.php/cje-rce/article/view/2446

Community for Advancing Discovery Research in Education. (2017). *Emerging design principles for online and blended teacher professional development in K-12 STEM education.* Education Development Center.

Council of Canadian Academies. (2015). *Some assembly required: STEM Skills and Canada's economic productivity*. Council of Canadian Academies Expert Panel on STEM Skills for the Future.

Creswell, J. W. (2012). *Planning, conducting, and evaluating quantitative and qualitative research* (4th ed.). Pearson.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development.* Learning Policy Institute.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Ennis, R. H. (2016). Definition: A three-dimensional analysis with bearing on key concepts. In P. Bondy & L. Benacquista (Eds.), *Argumentation, objectivity, and bias: Proceedings of the 11th international conference of the Ontario society for the study of argumentation* (pp. 1–19). OSSA.

Fazio, X. (2009). Development of a community of science teachers: Participation in a collaborative action research project. *School Science & Mathematics, 109*(2), 95–107. https://doi.org/10.1111/j.1949-8594.2009.tb17942.x

Fazio, X., & Gallagher, T. L. (2018). Bridging professional teacher knowledge for science and literary integration via design-based research. *Teacher Development, 22*(2), 267–280. https://doi.org/10.1080/13664530.2017.1363084

Fazio, X., & Gallagher, T. L. (2019). Science and language integration in elementary classrooms: Instructional enactments and student learning outcomes. *Research in Science Education, 49*(4), 959–976. https://doi.org/10.1007/s11165-019-9850-z

Fernandes, G. W. R., Rodrigues, A. M., & Ferreira, C. A. (2020). Professional development and use of digital technologies by science teachers: A review of theoretical frameworks. *Research in Science Education, 50*(2), 673–708.

Goodnough, K. (2018). Addressing contradictions in teachers' practice through professional learning: An activity theory perspective. *International Journal of Science Education, 40*(17), 2181–2204. https://doi.org/10.1080/09500693.2018.1525507

Grierson, A. L., & Gallagher, T. L. (2009). Seeing is believing: Creating a catalyst for teacher change through a demonstration classroom professional development initiative. *Professional Development in Education, 35*(4), 567–584. https://doi.org/10.1080/19415250902930726

Guskey, T. R. (2002). Professional development and teacher change. *Teachers & Teaching, 8*(3), 381–391. https://doi.org/10.1080/135406002100000512

Guskey, T. R., & Yoon, K. S. (2009). What works in professional development? *Phi Delta Kappan, 90*(7), 495–500. https://doi.org/10.1177/003172170909000709

Hill, H. C., Beisiegel, M., & Jacob, R. (2013). Professional development research: Consensus, crossroads, and challenges. *Educational Researcher, 42*(9), 476–487. https://doi.org/10.3102/0013189x13512674

Hitchcock, D. (2018). Critical thinking. In E. N. Zalta (Ed.), *The Stanford encyclopedia of philosophy* (Fall 2020 ed.). https://plato.stanford.edu/archives/fall2018/entries/critical-thinking/

Hodges, C., Grant, M., & Polly, D. (2013, March). Beyond one-shot workshops: Three approaches to STEM teacher professional development. In *Society for information technology & teacher education international conference* (pp. 4795–4800). Association for the Advancement of Computing in Education.

Hotze, A., Gijsel, M., Vervoort, M., Peters, S., & Post, A. (2020). Preparing teacher educators for language-oriented science education: Design and impact of a professional development program. In *Edulearn20 proceedings* (pp. 636–643). IATED.

Krajcik, J. S., & Mun, K. (2014). Promises and challenges of using learning technologies to promote student learning of science. In N. Lederman & S. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 337–360). Routledge/Taylor & Francis.

Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In N. Lederman & S. Abell (Eds.,), *Handbook of research on science education* (Vol. 2, pp. 889–909). Routledge/Taylor & Francis.

Maeng, J. L., Whitworth, B. A., Bell, R. L., & Sterling, D. R. (2020). The effect of professional development on elementary science teachers' understanding, confidence, and classroom implementation of reform-based science instruction. *Science Education, 104*(2), 326–353.

McMillan, J. H. (2004). *Educational research: Fundamentals for the consumer* (4th ed.). Pearson.

Merriam, S. (2009). *Qualitative research: A guide to design and implementation.* Jossey-Bass.

Mutch-Jones, K., Hicks, J., & Sorge, B. (2022). Elementary science professional development to impact learning across the curriculum. *Teaching and Teacher Education, 112*, 103625. https://doi.org/10.1016/j.tate.2021.103625

National Academies of Sciences, Engineering, & Medicine. (2015). *Science teachers learning: Enhancing opportunities, creating supportive contexts.* National Academies Press. https://doi.org/10.17226/21836

National Research Council. (2013). *Next generation science standards: For states, by states.* National Academies Press. https://doi.org/10.17226/18290

National Science Teaching Association. (2020). *NSTA district professional learning packages.* https://www.nsta.org/nsta-district-professional-learning-packages

Ontario Ministry of Education. (2008). *Ontario curriculum grades 9 and 10: Science.* http://www.edu.gov.on.ca/eng/curriculum/secondary/science910_2008.pdf

Ontario Ministry of Education. (2022). *Science and technology.* https://www.dcp.edu.gov.on.ca/en/curriculum/science-technology

Organization for Economic Co-operation & Development. (2017). *The OECD handbook for innovative learning environments.* OECD Educational Research & Innovation. https://doi.org/10.1787/9789264277274-en

Owston, R., Wideman, H., Murphy, J., & Lupshenyuk, D. (2008). Blended teacher professional development: A synthesis of three program evaluations. *The Internet & Higher Education, 11*(3), 201–210. https://doi.org/10.1016/j.iheduc.2008.07.003

Penuel, W. R., Fishman, B., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal, 44*(4), 921–958. https://doi.org/10.3102/0002831207308221

People for Education. (2019). *Connecting to success: Technology in Ontario schools.* https://peopleforeducation.ca/report/connecting-to-success-technology-in-ontario-schools/#chapter10

Peterson, A., Dumont, A., Lafuente, M., & Law, N. (2018). *Understanding innovative pedagogies: Key themes to analyse new approaches to teaching and learning.* OECD.

Polly, D., & Hannafin, M. J. (2010). Reexamining technology's role in learner-centered professional development. *Educational Technology Research & Development, 58*(5), 557–571. https://doi.org/10.1007/s11423-009-9146-5

Psillos, D. (2017). Development of a blended learning program and its pilot implementation for professional development of science teachers. In P. Anastasiades & N. Zaranis (Eds.), *Research on e-learning and ICT in education: Technical, pedagogical and instructional perspectives* (pp. 189–200). Springer. https://doi.org/10.1007/978-3-319-34127-9

Riggs, I. M., & Enochs, L. G. (1990). Toward the development of an elementary teacher's science teaching efficacy belief instrument. *Science Education, 74*(6), 625–637. https://doi.org/10.1002/sce.3730740605

Sandholtz, J. H., & Ringstaff, C. (2016). The influence of contextual factors on the sustainability of professional development outcomes. *Journal of Science Teacher Education, 27*(2), 205–226. https://doi.org/10.1007/s10972-016-9451-x

Sandoval, W. A. (2015). Epistemic goals. In R. Gunstone (Ed.), *Encyclopedia of science education* (pp. 1–6). Springer.

Sinclair, M., & Owston, R. (2006). Teacher professional development in mathematics and science: A blended learning approach. *Canadian Journal of University Continuing Education, 32*(2), 43–66. https://doi.org/10.21225/D52C75

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences.* Sage.

Thompson, J., Hagenah, S., Kang, H., Stroupe, D., Braaten, M., Colley, C., & Windschitl, M. (2016). Rigor and responsiveness in classroom activity. *Teachers College Record, 118*(5), 1–58. https://www.tcrecord.org, ID No. 19366.

Wayne, A. J., Yoon, K. S., Zhu, P., Cronen, S., & Garet, M. S. (2008). Experimenting with teacher professional development: Motives and methods. *Educational Researcher, 37*(8), 469–479. https://doi.org/10.3102/0013189x08327154

Wilson, S. M. (2013). Professional development for science teachers. *Science, 340*(6130), 310–313. https://doi.org/10.1126/science.1230725

Windschitl, M. (2009, February). Cultivating 21st century skills in science learners: How systems of teacher preparation and professional development will have to evolve. In *National Academies of Science workshop on 21st century skills*. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_072614.pdf

Zhu, C., & Wang, D. (2014). Key competencies and characteristics for innovative teaching among secondary school teachers: A mixed-methods research. *Asia Pacific Education Review, 15*(2), 299–311. https://doi.org/10.1007/s12564-014-9329-6

Xavier Fazio is a professor in the Department of Educational Studies, Faculty of Education at Brock University. Dr. Fazio's research broadly entails science and environmental sustainability education, teacher education and development, curricular innovation, instruction and assessment in science education. His research in Canada also connects to partnerships with researchers in the USA, European Union, Brazil, and Australia. Dr. Fazio's research has been supported with funding from the Social Sciences and Humanities Research Council of Canada (SSRHC), and various government agencies, industry, and educational associations. Currently, he is leading a multi-year Insight Grant from SSHRC examining how to connect school science to local communities using place-based perspectives to better promote meaningful engagement for science students. He currently is serving as Associate Editor for Journal of Science Teacher Education.

Kamini Jaipal-Jamani is a professor in Science Education in the Department of Educational Studies, Faculty of Education at Brock University. Her research and writing focus on science teaching and learning, technology integration, and teacher professional development. She has been involved in research partnerships with local school boards, professional teacher associations, and international organizations to support teacher and faculty professional development. Other professional activities include serving on the program committee of the Society for Information Technology and Teacher Education (SITE) and being a Lead Editor for the international journal, Cultural Studies in Science Education.