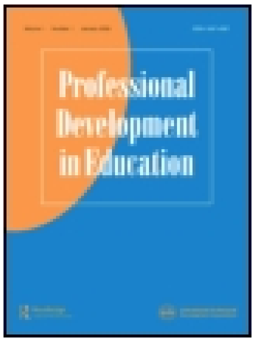

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Examining the sustainability of teacher learning following a year-long science professional development programme for inservice primary school teachers

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This two-year, mixed-methods study explored teacher learning during a year-long professional development programme and during the year following the programme. The study examined patterns of change in primary school teachers' inquiry practices, inquiry beliefs and physical science content knowledge during both years as well as the effects of school-level and individual-level factors on these changes in the year following the programme. Fifteen fourth-grade through sixth-grade teachers from three low-performing US schools participated. Results indicated that the programme was effective in advancing teacher change during the programme year, as scores in all three measures increased at statistically significant rates. Only content knowledge scores increased significantly in the year following the professional development. A combination of school-level and individual-level factors impacted the year 2 changes. School-level factors were: having supportive same-grade teams and/or a supportive mentor who advocated inquiry science and who prioritized science as a subject; principal prioritization of science; and having easy access to and training in the use of relevant materials. The primary individual-level factor was the degree of teachers' willingness and readiness to change beliefs in fundamental ways. Implications for professional development providers and school administrators are discussed.

Keywords: professional development; teacher beliefs; science education; school context; school factors; primary school education

Introduction

Building on previous national reform documents, the recent US documents *A Framework for K–12 Science Education* (National Research Council [NRC] 2012**)** and *Next Generation Science Standards* (*NGSS*) (NGSS Lead States 2013) advocate a new vision for school science education. These documents focus on achieving student facility with scientific practices such as asking scientific questions, planning and carrying out investigations, and analysing and interpreting data, in addition to fostering deeper levels of science disciplinary knowledge. Further, emphasis is placed on embedding the crosscutting concepts of science (e.g. patterns, cause and effect, structure and function) into student science learning. The science practices

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prioritize student use of evidence when making scientific claims, developing and using models, and using mathematical connections. For teacher practice, this means using instruction that promotes a deep understanding of scientific practices in addition to emphasizing depth over breadth in subject matter.

'Inquiry' teaching and learning encompasses many of the scientific practices outlined in the *Framework* and *NGSS* and is the focus of this study. Inquiry's defining feature is the process of observing and using evidence to create scientific explanations. Inquiry can be defined as 'a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena; in doing so, students acquire knowledge and develop a rich understanding of concepts, principles, models, and theories' (NRC 1996, p. 214). Student questions and investigations drive science learning in inquiry-based classrooms. Students, with various degrees of guidance, ask scientific questions and use investigations to advance their science learning. Inquiry can be implemented in numerous ways in the classroom. Teachers may provide more or less direction, depending on their learning objectives and on student preparation. While there is some debate on the merits of inquiry teaching for student learning (for example, see Furtak *et al.* 2012, Mcconney *et al.* 2013), in this article we use the inquiry approach as a tool for our ultimate goal of assessing the impact of professional development (PD) on teachers' adoption of science education teaching reforms and the sustainability of these changes.

The literature has identified the critical importance of teacher PD for preparing teachers to successfully implement science education reforms and to improve student outcomes (National Research Council 1996, Hewson 2007, Shymansky *et al.* 2013, Trygstad *et al.* 2013). Much research has found that in order for teachers to shift their science teaching practices, teacher PD must focus on teachers' beliefs about the value and feasibility of teaching through reform practices such as inquiry. The PD also must provide experiences that increase teachers' sense of preparedness and skill in teaching through reform practices (van Driel *et al.* 2001, Loucks-Horsley *et al.* 2003).

While content knowledge change can be straightforward and can occur relatively easily through experiences such as content-oriented PD programmes (Gess-Newsome 2003), changes in beliefs are much more difficult to impact (Pajares 1992, Thompson and Zeuli 1999, Loucks-Horsley *et al.* 2003). Belief change through PD has been the focus of recent research in PD. Beliefs, by their nature, are conservative and resistant to change, even when all evidence points toward the benefits or even necessity of change (Pajares 1992, Thompson and Zeuli 1999, Loucks-Horsley *et al.* 2003). Well-designed PD has been shown to promote significant shifts in beliefs, shifts in sense of preparedness and enhancement of science content knowledge (Loucks-Horsley *et al.* 2003). These, in turn, impact changes in teaching practices toward reform instruction (Akerson and Hanuscin 2007, Duschl *et al.* 2007). This research reveals the complexity of understanding and impacting teacher learning.

The literature on the PD elements that effectively influence teacher learning during science-based PD is substantial (Hewson 2007). These critical elements include long-term engagement, collaboration with other teachers, an emphasis on student learning and connectivity to classroom practices (Gess-Newsome 2001, van Driel *et al.* 2001, Loucks-Horsley *et al.* 2003), all with a focus on providing opportunities for active learning (Hewson 2007).

Long-term programmes have shown substantial success in impacting teachers' beliefs and practice. Programmes that occurred over several years (for example, Akerson and Hanuscin 2007) and/or over many hours of PD (for example, Banilower *et al.* 2007) resulted in changes in beliefs and ideas about inquiry instruction, and perceptions of preparedness to teach through inquiry, along with evidence for implementation of inquiry practice in the classroom. Banilower *et al.* (2007), for example, found these changes after 130 hours of PD. In addition, Shymansky *et al.* (2010) found a significant positive relationship between the number of PD hours and student gain scores on national achievement tests.

Many PD programmes, however, do not have the funding for long-term engagement, putting into question the sustainability of the teacher learning that occurs during the course of the programme. Some organizational literature has investigated the sustainability of teacher learning. This research has revealed that collegial support, organizational support and policy-based support of PD goals are central elements to sustained teacher change (Guskey 2000, Loucks-Horsley *et al*. 2003, Johnson *et al.* 2010). In this study, we aimed to contribute to this literature by investigating the effects of a year-long, 88-hour ('medium-length') inquiry and science content-oriented PD programme on primary school teacher learning. Specifically, we investigated the factors necessary to sustain teacher learning in the year following a year-long, medium-length PD experience.

Primary school science teaching

Student learning is ultimately impacted by teacher practice in the classroom. Teacher practice, in turn, is linked in complex and powerful ways to teachers' content knowledge and beliefs (Keys and Bryan 2001). The majority of primary school teachers have low content knowledge in science (Rice 2005, Duschl *et al.* 2007), making it a subject in which they feel unprepared and lack confidence (Schoeneberger and Russell 1986, Appleton and Kindt 1999). These feelings discourage them from teaching science, especially through reform-based methods such as inquiry (Schoeneberger and Russell 1986). Enhanced content knowledge is necessary for reform-based science teaching (Crawford 2000). Davis (2004) found that if primary teachers had adequate science content knowledge they were more likely to teach authentic inquiry-based science.

Even though teachers report that they value inquiry-based practices (Marshall *et al.* 2009, Trygstad *et al*. 2013), they often believe inquiry is too difficult to implement in the primary classroom (Wee *et al.* 2007). Similarly, teachers often claim scientific inquiry is time consuming, costs too much and is too advanced for students (Bybee 2000). Such beliefs about inquiry teaching and learning often affect teachers' willingness to implement inquiry in their classrooms (Ramey-Gassert and Shroyer 1992, Coble and Koballa 1996, Keys and Bryan 2001).

Primary school students, then, are not receiving the quantity or quality of science instruction described in science reform documents (Fulp 2002, Trygstad *et al*. 2013). Science is de-prioritized as a subject, and little time is typically devoted to this subject compared with other subjects (Trygstad *et al.* 2013). When science is taught, the norm is to use traditional practices such as teachers explaining a science idea to the whole class, whole-class discussion or students reading about science, even if teachers report that they value reform-based scientific practices (Marshall *et al.* 2009, Trygstad *et al*. 2013).

For the type of teaching necessary to achieve the goals of reform in the science classroom, teachers must alter their instructional practice. To effectively change teachers' practice in order to meet these goals, teachers must feel more prepared and be better skilled not only in teaching science as a subject, but in teaching it through inquiry. This means increasing teachers' content knowledge in science and shifting teachers' beliefs about the value and feasibility of teaching through inquiry-based practices (Pajares 1992, van Driel *et al.* 2001, Gess-Newsome 2001).

Research on the sequence of change between practice, beliefs and knowledge is mixed. Some studies suggest that successful change in practice is followed by belief change, as teachers are motivated to change after witnessing positive shifts in student learning (Pajares 1992, Guskey 2000, Gess-Newsome 2001). Other scholars report that there is little consistency as to which occurs first, and that it differs among individuals (Richardson 1994, Fennema *et al.* 1996). Increases in content knowledge are related to changes in teacher beliefs and practice, as shifts in one can affect shifts in the others (Kennedy 1998, Schoon and Boone 1998).

Study purpose

The primary goal of this study was to build on previous research in science teacher PD to investigate the factors involved in sustained learning following PD. While the literature has described effective elements of PD, there have been several calls for more long-term research on the continuation of learning in teachers' classrooms after the PD has been completed. For example, Webster-Wright (2009), in a comprehensive review of research on teacher PD, argued for more, in-depth research that connects the learning which occurs in PD programmes and the continued learning which occurs afterwards in teachers' classrooms and school environments. Other researchers similarly call for more research on the effects of school context on teachers' teaching practice and beliefs following PD (for example, Keys and Bryan 2001, Richardson and Placier 2001). This study was initiated in response to the calls for further research by investigating the factors involved in the sustainability of shifts in teachers' inquiry-based practices, inquiry-based beliefs and content knowledge in the year following PD.

Research questions

In the first phase of the study, mixed methods were used to examine changes in 15 primary school teachers' inquiry-based science practices, inquiry-based beliefs and content knowledge during a year-long PD programme. The PD goals were to provide teachers with the tools, knowledge and support for teaching and learning science through inquiry and to enhance teachers' physical science content knowledge. In the second phase of the study, the sustainability of these changes during the following school year was investigated. The influence of school-level, situated factors and teacher-level factors was examined. This study was guided by the following research questions:

(1) What changes occur in teachers' inquiry-based practices, inquiry-based beliefs and content knowledge during a year of professional development and a year of classroom practice?
(2) What impact do school-level factors have on the changes that occurred in teachers' inquiry-based practices, inquiry-based beliefs and content knowledge during the year after a professional development programme?

(3) What impact do individual-level factors have on the changes that occurred in teachers' inquiry-based practices, inquiry-based beliefs and content knowledge during the year after a professional development programme?

Methods

Professional development context

The Physical Science Inquiry Academy (PSIA) programme provided a year-long PD experience to fourth-grade through sixth-grade teachers from three schools in the study district that scored lowest in physical science on the state's standardized test. The 2008/09 cohort was the first group in this programme. The cohort participated in 88 hours of PD: a three-day summer institute and eight full-day, monthly Academy sessions that took place during the school week. Substitute teachers for the monthly Academy sessions, a teacher stipend and university credit were provided.

The key goals of the PSIA were to provide teachers with the tools for understanding, accepting and implementing inquiry-based science teaching and learning, and to enhance teachers' physical science content knowledge. The three-day summer institute focused on introducing teachers to inquiry through modelling, lesson adaptations and reflection. The 5E instructional model – Engage, Explore, Explain, Elaborate, Evaluate (Biological Sciences Curriculum Study 1997) – was the primary model of inquiry used throughout the programme. Teachers also experienced activities with different levels of inquiry, including confirmation, structured, guided and open inquiry (Banchi and Bell 2008, NRC 2000), and used scaffolds for conducting investigations. Teachers experimented with inquiry lessons throughout the institute and worked on adapting existing district science curricula to be more inquiry oriented. Discussions about student learning through inquiry and exploring implicit beliefs about inquiry spanned the institute.

In the morning the monthly academy sessions expanded on the inquiry experiences from the summer, and in the afternoon they focused on grade-level physical science content knowledge enhancement. Topics for the morning sessions (which focused on a different topic each month) included teaching science to special populations (English language learners, special education, and gifted and talented), management of science centres, use of science notebooks, reading/literacy connections with science and effective use of technology in science. These sessions were presented from an inquiry orientation, in which presenters modelled how to apply inquiry-based teaching and learning for that topic. Direct applications for teachers' classrooms were explicitly addressed. Further, teachers had opportunities to experience and practice each topic that was presented. The afternoons consisted of grade-level breakout sessions where instructors modelled the use of grade-specific inquiry lessons and associated kits. Here, teachers experienced using the lessons, and were provided with the necessary materials and supplies for their classroom. All of the physical science state core curriculum topics for each grade level were covered during the year.

The core staff for the PSIA were comprised of a university scientist who was also an education outreach specialist, the school district science specialist, the district primary school science specialist and a programme evaluator. Master teachers, curriculum and assessment specialists, and university education specialists were invited to teach topic-specific sessions throughout the programme. Further, teachers were provided with inquiry-based kits, activities and materials for all physical science topics in their grade-specific state science core curriculum, and received training in using these kits.

Research paradigm and design

The study used a longitudinal, mixed-model study design, integrating both quantitative and qualitative data. Data were collected over two years for the same participants. This methodology facilitated an examination of pattern development in teachers' inquiry-based practice, beliefs and content knowledge during the PD programme year and during the following year. This also enabled investigation of the contextual and individual factors that facilitated or impeded the maintenance of teacher learning in the year following the programme.

The study approach followed Tashakkori and Teddlie's (1998) parallel, mixed-model study design. In this model, mixing occurs within each stage of the study. Both confirmatory (quantitative) and exploratory (qualitative) research questions were asked, and both quantitative and qualitative techniques were used in data collection and data analysis.

Participants and school contexts

In year 1, data were collected from all 15 teachers who participated in the PSIA programme in the 2008/09 school year. Teachers included: six fourth-grade teachers (students aged 11–12), five fifth-grade teachers (students aged 10–11) and four sixth-grade teachers (students aged 9–10) from three different schools – Rivers, Sycamore and Watershed. In this article, pseudonyms have been used for all schools and teachers.

The three schools served low-income, linguistically diverse populations in one school district in the Mountain West. The schools were selected because they scored lowest in the district on the state-wide standardized science achievement tests and were deemed by the district science specialist to be in need of intervention through PD. In these schools, administrator focus was on improving test scores in language arts and mathematics because federal funding and certain punitive measures were based on scores in these subjects. As a result, science was not an academic priority for principals (and therefore for teachers) at these schools.

Participation in the PSIA was voluntary. Teachers from two of the schools, Watershed and Sycamore, were encouraged by their school administrators to participate. Teachers from Rivers received no encouragement from their school administration, and were recruited by one of the school's participating teachers.

All 15 teachers were invited to participate in year 2 of the study (the year following the PD). Of these, 12 teachers participated: six fourth-grade teachers, two fifth-grade teachers and four sixth-grade teachers (two teachers who did not participate had moved to administrative positions and one had left teaching). Three principals, one from each participating school, also participated in year 2. School district and university human subject (Institutional Review Board) approval were received for both years of the study.

Data collection and procedures

Quantitative data were collected using three instruments. The Reform Teaching Observational Protocol (RTOP) (Sawada *et al.* 2002) measures inquiry practice. Data were collected via classroom lesson observations by two independent observers. An inter-rater reliability of over 90% was reached for each observation. The Beliefs About Reformed Science Teaching and Learning (BARSTL) (Sampson *et al.* 2013) measures teacher beliefs about teaching and learning through inquiry. The Misconceptions-Oriented Standards-Based Assessment Resources for Teachers (MOSART) (Science Education Department of the Harvard-Smithsonian Center for Astrophysics 2006) assessments measure teachers' physical science content knowledge. Table 1 presents a data collection timeline. The collection time points were selected to provide sufficient time for shifts in teachers' practice, beliefs and content knowledge to occur.

Primary qualitative data sources were interviews with the teachers and their school principals. Questions assessed beliefs and understandings about inquiry, teachers' classroom practice and the impacts of school contextual factors on teacher change in practice and beliefs (teachers' content knowledge gain was not assessed through qualitative measures). The Teacher Beliefs Interview protocol (Luft and Roehrig 2007) informed the design of the interview questions. These collection time points were selected to provide sufficient time for teachers to experience change in their practice and beliefs, and to assess school-based impacts on this change (see Table 1).

Secondary qualitative data sources were the field notes collected at each lesson observation and PSIA programme session. Informal conversations with teachers were also recorded in the field notes.

Data analysis and integration

For quantitative data analysis, repeated-measures analyses of variance were used to look for patterns of change across the two years. Paired-sample *t* tests and polynomial contrasts were used to further assess changes between the data collection periods.

For qualitative data analysis, the constant comparative method (Glaser and Strauss 1967, Strauss and Corbin 1998) was used in reading the transcripts of the teacher and principal interviews, grouping similar responses and descriptions. The interviews were coded for evidence of teacher inquiry practice, inquiry beliefs and inquiry understandings as well as reasons for the changes or lack of changes. Colour coding was used to mark recurring themes across the data sources, and themes were identified for each teacher in the development of individual study profiles (Creswell 1998).

During quantitative and qualitative data integration, a case study was created for each teacher that combined and summarized data over time. A cross-case analysis was then conducted between cases. Similarities and differences were clustered into groups (Miles and Huberman 1994, Creswell 1998). Trends and patterns were established in: teachers' inquiry practice and beliefs; school-level (contextual) factors affecting programme impacts; and individual-level factors affecting programme impacts. Broader themes describing these trends and the experiences of inquiry practice and beliefs within the school contexts for each cluster were then

Table 1. Timeline for administration of study instruments and interviews.

	Interview						
Instrument	**Beginning of year 1 summer institute**	**Beginning of school year 1**	**Middle of school year 1**	**End of school year 1**	**Beginning of school year 2**	**Middle of school year 2**	**End of school year 2**
BARSTL (inquiry beliefs)	X			X			X
RTOP and field notes (inquiry practice)		X	X	X	X		X
MOSART tests (content knowledge)	X			X			X
Interviews – teachers		X			X		X
Interviews – principals						X	

developed (Miles and Huberman 1994). Finally, in order to establish further validity and trustworthiness of the data, member checks were conducted with the participants who were interviewed in both years by sending a draft of the themes for their consideration, and further refining the themes based on their feedback (Guba and Lincoln 1989).

Results

Research question 1

The first research question examined the changes that occurred in teachers' inquiry-based beliefs, inquiry-based practices and content knowledge during a year of PD and during the following year of classroom practice. The quantitative results are reported first, followed by qualitative data that elaborate on these quantitative data. The qualitative data are based on interviews with 15 teachers in year 1 and with 12 of these teachers in year 2. The teacher quotations in this section were selected from these interviews as representative of the study findings. Similarly, the graphs are provided as simple visual representations of trends in the data.

Quantitative data results

Because the participant number in this study is low, general trends from the data analysis are reported. More complete statistical results are presented in Appendix 1.

The results from the RTOP instrument that measured inquiry practice revealed steady increases in inquiry teaching practice during the PSIA participation year, with the greatest increase occurring between autumn and winter of that year. In year 2, scores remained fairly constant between autumn and spring. Scores on the BARSTL instrument, which measured teachers' beliefs about teaching and learning through inquiry, increased toward more inquiry-based beliefs over both years but the rate was greater in year 1 than in year 2. Finally, teachers' content knowledge scores increased slowly and steadily over the two years. See Figure 1 for trends in all three measures across years 1 and 2.

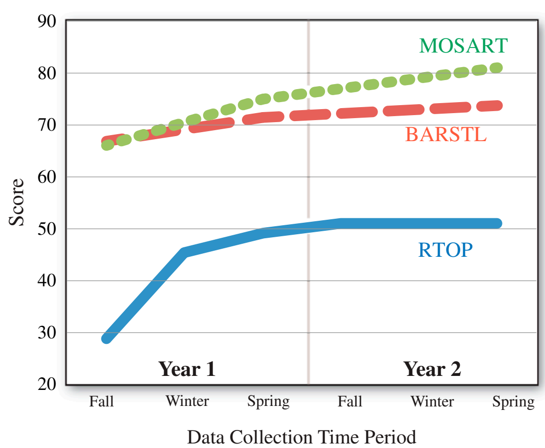

Figure 1. Change in teachers' RTOP, BARSTL and MOSART scores in years 1 and 2.

Qualitative data results

The qualitative findings for teacher practice change showed that, especially for the teachers with little previous inquiry training, participation in the PSIA contributed to gains in their use of inquiry teaching and learning over the participation year and continued into the following year. For example, many teachers shifted in their comfort level and implementation of more student exploration in class. There was an increase by the end of year 2 in the number of teachers who also incorporated reform-based terminology, such as ‘exploration’ or ‘investigations’, when discussing inquiry.

However, the data also revealed that by the end of year 2 teachers typically incorporated only the first two phases of the 5E instructional model, the Engage and Explore elements, but not the rest of the model (the Explain, Elaborate and Evaluate components). Most of the teachers’ practice was still limited to ‘exploration-type’ and ‘hands-on’ (rather than ‘minds-on’) activities. Many of the teachers who defined inquiry before the PSIA year as ‘hands-on’ or ‘discovery’ learning continued to do so after the programme, indicating a lack of a thorough (or sophisticated) understanding of inquiry. So teachers’ practice changed towards greater, although incomplete, inquiry practice during the participation year. The trend continued into the year following participation, indicating that changes which occurred during the programme were sustained post participation.

The qualitative data for teacher beliefs about teaching and learning through inquiry provided insights into some of the belief changes found in the BARSTL instrument results. Ten of the 12 teachers interviewed in both years had perceived a change in their role as a teacher from more traditional views of teacher as information provider to more student-centred views of teacher as facilitator and guide for student investigations. For example, Rich explained his approach to student science learning prior to PSIA participation as:

> My typical approach last year was ‘Bill Nye, The Science Guy’ … Last year, I felt it was all up to me as the teacher to present and they had to filter through what was most important. Last year I had a science folder, and they would have homework on one side and completed [homework] on the other. They would move it from one side to the other … I admit that a lot of it would become remedial. I’m sure they would get bored with it because of all the worksheets. (Rich, Interview 1)

He described his change after the PSIA summer institute and several monthly Academy sessions:

> But now what I do is … an introduction, then I take it a step further and I go into the inquiry. We start to ask questions. We start to do experimentation and I ask them to do some research at home. I’ve really tried to focus more on shifting the accountability and the responsibility to them. (Rich, Interview 1)

Thus, the qualitative data supported the quantitative findings of increased beliefs favouring inquiry-oriented teaching.

In sum, the results from the first research question revealed increases in all measures across the two years. In year 2, these trends slowed for inquiry beliefs and practices. The qualitative data corroborated the quantitative data, and provided further descriptions of the shifts in teachers’ beliefs about inquiry teaching and learning and in their perceptions of changes in their practice. While participants’ change in practice, beliefs and content knowledge in year 1 can be attributed to their participation in the PSIA, research questions 2 and 3 investigated the impact of school-level and individual-level factors on the year 2 results.

Research questions 2 and 3

Research questions 2 and 3 examined the school and individual factors that impacted participants' change in the three measures in the year following the PD programme. In this study, we focused on providing explanations for change in practice. The results revealed that a combination of school-level and individual-level factors impacted the year 2 changes.

School-level factor 1: collaborative same-grade teams

The most influential school-level factor for continued teacher change in inquiry practice was having collaborative same-grade teams and/or a supportive mentor who advocated inquiry science and prioritized science as a subject. Each of the three study schools showed similar patterns; we therefore report the results for one school, Sycamore, and the stark contrast between the fourth-grade and sixth-grade teams at this school. Two fourth-grade teachers, Rachel and Danielle, participated in the PSIA. The fourth-grade team at Sycamore was highly collaborative and all four teachers were supportive in their attitudes toward inquiry science and prioritized science teaching. The data suggest that this group incorporated learning from the PSIA as a team. As Rachel described:

> Danielle and I incorporate learning from PSIA together because we took the programme together. We have two other people on our team who are doing 'mock rocks' [artificial rocks that simulate real rocks] this year with us because we did this last year at PSIA. I feel that our team is very receptive of anything that we brought back from [PSIA]. It's always the grade-level team … it's a good team. (Rachel, Interview 2)

Further, Rachel, an experienced teacher, served as the informal fourth-grade team leader at this school. She strongly supported inquiry teaching: 'I think all of us as human beings learn best from inquiry-based learning, and it goes along so well with that kinesthetic approach that so many younger kids need' (Rachel, Interview 2).

Rachel served as mentor to Danielle, who was younger and less experienced. The results suggested that Rachel's support of inquiry teaching and science as a subject influenced Danielle in her inquiry practice. Rachel's RTOP scores at baseline were higher, and ended higher, than all of the Sycamore teachers who participated in the PSIA. Danielle's scores were initially significantly lower than Rachel's but rose steadily over the two years to surpass Rachel's highest score. The results suggest that Rachel's mentorship, along with the entire fourth-grade team's support for inquiry and prioritization of science, impacted Danielle's substantial increase in her inquiry practice scores.

Interestingly, Rachel's scores increased over the two years, although not as substantially as Danielle's. Although Rachel had her team's support for inquiry teaching, she probably lacked a team member skilful or knowledgeable enough in inquiry to push her to change her practice in ways that would have raised her scores further.

In contrast, the three-person sixth-grade team at Sycamore had no interaction with one another about science or inquiry teaching in year 2, despite both Clair's and Rich's participation in PSIA. Clair explained:

> Unfortunately, one member of our team is not a very good team player and wants to be more isolated … it's hard … The other sixth-grade teacher has done her own thing too, I've tried to pull her in, but she's just kind-of an island of her own too. If you don't have buy-in from everybody, it doesn't work. (Clair, Interview 2)

When asked about team collaboration, Rich corroborated Clair's statements: 'I just kind of do my own thing' (Rich, Interview 2). Further, Clair reported that she did not know whether Rich had implemented any of the PSIA activities, evidencing the lack of communication about science in this same-grade team. This lack of collaboration had an effect on these teachers' year 2 inquiry practices, as evidenced by their RTOP scores. As Figure 2 shows, when averaged across grade level, the Sycamore teachers' scores rose in the first year. However, in the second year, the sixth-grade teachers' scores showed no substantial growth; rather, there was some decline in scores. In contrast, the fourth-grade team's RTOP scores continued to rise in year 2.

School-level factor 2: materials and training on their use. Data analysis revealed that providing teachers with materials and training on their use was critical for inquiry practice change in year 1 and contributed to the maintenance or increase in scores in year 2. A number of findings were related to teachers' need for materials, supplies and training at the low-income schools in this study.

The teachers from all three schools reported having a significant need for materials before the programme began. Mary, for example, stated: 'The idea that there would actually be materials available was a real big incentive [to join PSIA] because one of my biggest frustrations has been trying to get science materials together' (Mary, Interview 1). The teachers indicated that the PD programme was a recognized source for the necessary materials and training. For example, in her year 2 interview, Kristin explained: 'I got so many great materials from PSIA that I really have not been in need of any science materials.'

Results also revealed that teachers had been reluctant to ask principals for funds for science materials. Principal B explained: 'If we were putting a primary emphasis on science like we do in reading and math, they'd probably be asking. But honestly, I'm not asked about [purchasing science materials].'

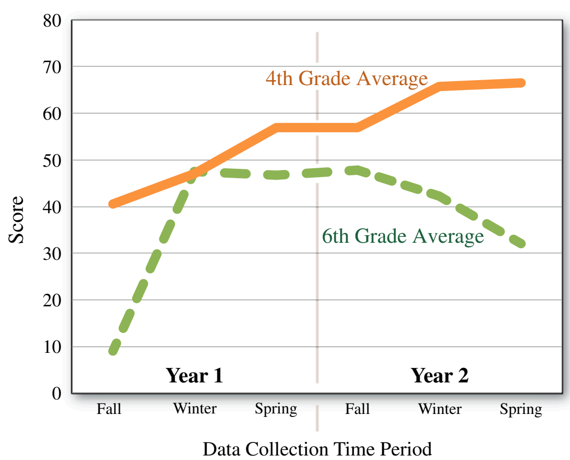

Figure 2. RTOP scores by teacher at Sycamore.

Finally, results indicated that gaining relevant materials and training facilitated teaching through inquiry. For example, Clair explained:

> I have the supplies and stuff now. That's the tub for light, it's labeled, and so I was able to just grab it, and I had everything there. I would say this year I've done probably as much or more inquiry-based lessons as I did [during the PSIA year] because … I finally had the supplies because I didn't actually have anything before. (Clair, Interview 2)

School-level factor 3: principal prioritization of science

Principal prioritization of science was also found to impact teachers' inquiry practice scores. This impact, however, was on teachers' average practice scores by school rather than on teachers' change scores. Teachers' average RTOP scores were proportionally higher in schools with greater principal prioritization and support of science.

Nonetheless, principal prioritization indirectly influenced teacher change in practice through mandating or encouraging same-grade team collaboration in science. The Watershed teachers (with high principal prioritization of science) were higher in teacher inquiry scores and time spent discussing science in same-grade meetings, while the Rivers teachers (with low principal prioritization of science) were notably lower in both of these outcome measures. These results suggest that while principal prioritization of science is an important school-level factor, same-grade collaboration may be more influential in inquiry practice change. Thus, having effective same-grade teams with strong team leaders can mitigate the effects of an unsupportive administrator.

Individual-level factor: degree of willingness to shift beliefs in fundamental ways

Teachers' willingness and readiness to change their inquiry beliefs was related to their shifts in inquiry practice. More specifically, the study results indicated that the degree to which teachers were ready and willing to change their inquiry beliefs in fundamental ways was related to the amount of change in their inquiry scores in the year following PD. Analysis revealed three discreet levels of willingness and readiness to change. Figure 3 shows the inquiry practice scores of a teacher representative from each level.

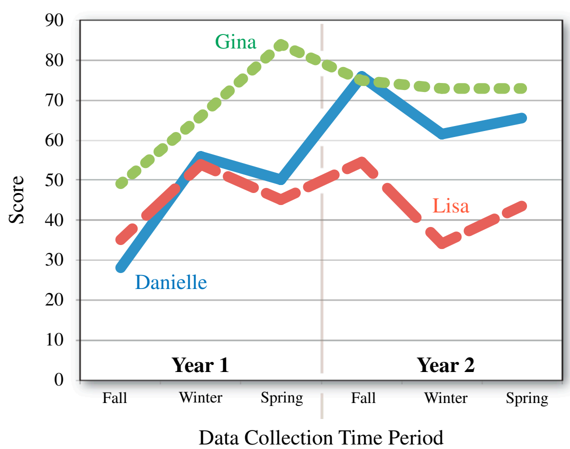

Figure 3. The inquiry practice (RTOP) scores of Lisa (level 1), Gina (level 2) and Danielle (level 3).

Level 1: entering the programme with a desire to gain new activities and resisting a paradigm shift toward inquiry. Several teachers entered the programme wanting to gain new materials and activities to use in their classroom. Even though these teachers claimed to support inquiry, their descriptions of their experience during the PSIA and the following year revealed that they were not yet willing to change their beliefs about teaching and learning to reflect inquiry ideologies. The RTOP scores for level 1 teachers increased by 20 points at some period during the two years; however, by the end of year 2, these scores tended to return to their year 1 starting point. For example, in her year 1 interview, Lisa expressed the following:

> I just would like more information on ways to successfully teach the students to get them to retain … How do I get them to remember that [content] past the few minutes we're doing this lesson or activity? I wish I had just a really specific bank of activities … Like, 'Here are three activities to teach this objective and here's this center.' (Lisa, Interview 1)

In her year 2 interview, however, some of Lisa's statements suggested that she had begun recognizing the need for a shift in her beliefs. Further, she recognized the difficulty of changing one's belief system and teaching practice. She began to reflect and talk about the change process, although she had not yet begun to undertake change:

> I think I am drawing a lot from the experience of last year, but I think it will take a while to process … It's like every month, 'Okay, now you need to do this.' Are you kidding me? I've already changed so many other things or adapted … A significant change like this takes years and years. So, there is no expectation at all [on my part] that it would have happened in just a year. (Lisa, Interview 2)

Lisa's inquiry practice scores, shown in Figure 3, reflected a resistance to changing her beliefs in fundamental ways during the study period. While her RTOP scores fluctuated over the two years, her practice did not change in a sustained way, and ended in the same place where she started at the beginning of the programme.

Level 2: entering the programme with an interest in improving teaching techniques and expressing a willingness to reflect on one's own teaching practice. Teachers in the level 2 category desired an improvement in their teaching practices by gaining new instructional techniques. In addition, and as opposed to the level 1 teachers, these teachers demonstrated a willingness to reflect on their practice and an openness to altering their beliefs. The RTOP scores of all three level 2 teachers increased 30 points over the course of the two study years. For example, when asked about her goals for joining PSIA, Gina responded:

> Do more inquiry. Raise [standardized test] scores. Develop in the kids a real love of science so that, no matter what happens down the road, it will be something they are curious about and want to learn more about independently. (Gina, Interview 1)

She described some of the changes she noticed in her own beliefs and science teaching practice after the summer institute and several PSIA sessions:

> I try to do more inquiry now. Start with a question rather than jumping right into 'This is the content you need to know.' I am trying harder to do that … it's something I need to do more of. (Gina, Interview 1)

As shown in Figure 3, Gina's RTOP scores reflected her shifts over the two years. Her scores increased substantially in year 1. While her scores declined slightly in year 2, they were significantly higher (around 25 points) at the end of the study than at the beginning. This suggests that her willingness and readiness to shift toward more inquiry-oriented beliefs influenced her RTOP score gains to a greater extent than occurred for the level 1 teachers. Still, level 2 teachers such as Gina did not experience a fundamental paradigm shift in their beliefs.

Level 3: regardless of initial goals for the programme, having a willingness and readiness to change in ways that resulted in a fundamental orientation shift toward inquiry. The level 3 teachers came to the programme with varying expectations; however, all experienced a fundamental shift in their beliefs about the effectiveness of student learning through inquiry. As reflected in their RTOP scores, which increased between 20 points and nearly 50 points at some point during the two years, these teachers were implementing inquiry into their practice.

Danielle, for example, was open and eager to gain content knowledge and change her teaching beliefs and practices through the PSIA. In year 1, she described her teaching practice as teacher-centred and her hopes for learning more about inquiry:

> I use direct instruction just because I think that's what science is for the most part. Of course there are the experiments to go with it, but most of it is direct instruction … I don't know so much about science and how to get it ingrained in their head … I found that with the first unit, with weather, that I don't know how to make it inquiry-based. (Danielle, Interview 1)

When asked what she hoped to gain from the PSIA, she explained:

> I'm all about getting help because I need it and I know that I need it … [I want] to learn more about [science], and I do want the kids to do it on their own just to see if they can justify it, right or wrong … Enthusiasm for [science] is the main thing, and understanding [science content] a little bit more. And you know, I would like to do some experiments. (Danielle, Interview 1)

In year 2, Danielle had changed in her beliefs about how students learn, and gained an understanding of how she could teach through inquiry. In reflecting about the changes she had experienced in her science teaching, she described more inquiry-based instruction and her conscious effort to create a more student-centred classroom:

> Because of [PSIA] I'm willing to do [science] and try new things. I want the kids to like science, like to find the answer, know that it's okay to be wrong … Science is … an investigation … I'm starting to let them explore on their own. That was a big thing from last year, me letting go, which was such a big control issue for me. I think it's getting better for me personally. (Danielle, Interview 2)

As Figure 3 shows, Danielle's RTOP scores increased nearly 50 points during the two years. This substantial increase reflects her willingness to shift toward a more inquiry-based orientation. It was the quality of the belief change, then, that distinguish level 3 and level 2 teachers, which influenced their practice to be more inquiry oriented.

Summary of results

Participation in the PSIA PD programme impacted teachers' inquiry-based practice, inquiry-based beliefs and physical science content knowledge. Teachers' scores in all three outcome measures rose during the PD year. When averaging teachers' scores, these increases were sustained or further increased in the year following the programme. A combination of school-level and individual-level factors influenced the year 2 results. Same-grade collaboration, support and/or mentorship in teaching through inquiry along with having a personal willingness to change in fundamental ways appeared to be most impactful. In addition, materials and adequate training in their use were essential for growth in inquiry implementation in year 1 and contributed to the maintenance of the growth in year 2. Finally, while the influence of school administration was an important school-level factor for sustaining teacher learning, effective same-grade teams mitigated the effects of an unsupportive principal.

Discussion and conclusions

This study examined teacher learning during an 88-hour ('medium-length'), year-long PD programme for primary school teachers and the maintenance or sustainability of the learning in the year following the programme. The learning that occurred in the PD year was either maintained or continued to increase in the year following the programme, when averaging across participants' scores. While the literature is clear that long-term science PD – especially PD that occurs over several years – provides the greatest opportunity for sustaining shifts in teachers' reform-based beliefs and practices (for example, Johnson *et al.* 2010), several factors influenced the sustainability of teachers' learning in this medium-length programme.

The results from this study suggest that, in the absence of participation in long-term PD (or with no continued support from a PD programme of any kind), maintenance of the learning is most influenced by same-grade collaboration, support and/or mentorship along with having a personal willingness to change in fundamental ways. The literature supports the importance of each of these factors on teachers' implementation of reform-based science practices.

Research has shown the influential role colleagues in schools play on one another's science teaching practice (Ishler *et al.* 1996, Appleton and Kindt 1999, Richardson and Placier 2001). Appleton and Kindt (1999), for example, found that collegial support was related to novice primary school teachers' willingness to try non-traditional science instructional methods. In many of the studies, however, it was unclear whether the collegial collaboration described was specific to same-grade teams. The importance of receiving materials and training on these materials supports Appleton and Kindt (1999), who found that the availability and accessibility of resources for science and organization of the resources at primary teachers' schools determined their choice of science instructional practices and the types of science topics covered. Trygstad *et al.* (2013) found that resource-related issues, such as inadequate funds for purchasing science equipment and supplies, lack of science facilities and inadequate materials for individualizing science instruction, were a serious hindrance for primary school teachers in using reform-based practices such as those described in the *Framework* and *NGSS*. This finding highlights the need to provide materials and training on these materials as part of PD programmes serving teachers.

Finally, the results are consistent with other research advocating strong alignment between the goals of PD, school administration and the district in order for teachers to successfully implement reform-based practices (Sparks 2002). For example, Johnson (2007) concluded that in order for middle school teachers to use more reform-based science practices, administrators must provide resources and protection from outside forces – including district pressures – that can hinder teachers' attempts to improve their practice. Guskey (2002, p. 47) explained that a 'lack of organizational support and change can sabotage any PD effort, even when all the individual aspects of PD are done right'.

The impact of the individual-level factor – teachers' degree of willingness to change in fundamental ways – on science teachers' practice is consistent with Richardson and Placier (2001), who concluded that teachers' willingness to change in practice might depend on their attitudes and beliefs toward teaching and learning. This finding also lends support to other literature which has found that changes in teacher beliefs are explanatory factors in teacher shifts in practice (Pajares 1992, van Driel *et al.* 2001). Interestingly, teachers' statements prior to the PSIA programme did not always reflect their willingness to change their beliefs or the extent to which their practice scores changed in the programme year or the following year. These findings suggest that teachers' comments prior to beginning a PD programme are not enough to predict who might benefit the most from such a programme. Teachers may be influenced by numerous experiences that affect their beliefs and practices during and after PD. They may be influenced, for example, by the ways in which their students respond to the new instructional practices (Loucks-Horsley *et al.* 2003), by their colleagues or by their administration, among other influences.

Based on these findings, the following conclusions can be drawn about the factors involved in sustaining teacher learning from a PD experience. It should be noted that the study results have limited generalizability due to the relatively small study population of 15 teachers, three principals and three schools. These small numbers are typical, however, in research on teacher PD. Conclusions include the following:

- Advances in teacher practice and changes in beliefs during a PD programme can be sustained and continued once the programme is over. School supports are required to maintain or enhance this learning.
- Not all teachers are open or willing to alter beliefs and practice, and naturally for these teachers it is unlikely that PD will result in substantial changes. However, it is not always clear at the beginning of a project which teachers will embrace change, based on their demographic profile or self-described goals.
- Materials and training in their use are critical for change toward inquiry teaching and learning in schools that have few science materials and supplies and/or training in using them.
- Effective same-grade teams with strong team leaders can mitigate the effects of an unsupportive administrator in sustaining change.
- Fundamental change in teacher beliefs and practice is a gradual and challenging process. One year of PD is not sufficient to advance comprehensive change in most teachers' practice or beliefs.
- Only some parts of the strategies modelled in a PD programme that involve belief change are likely to be integrated in the year following PD. For example, incorporating all five phases of a 5E instructional model may not occur in only one or two years. Further, implementation depends on the strategies teachers are most frequently exposed to during PD (Grigg *et al*. 2013).

Implications for PD providers, school administrators and funders

The study results have implications for PD providers, school or district administrators and funders with respect to supporting sustained change in teacher beliefs and practice following science teacher PD. These implications have the potential for extension to different types of PD programmes and school settings beyond those in which the study took place – a medium-length, one-year programme in low-achieving schools. In addition, they also could be extrapolated to the more recent reform efforts outlined in the US documents *A Framework for K–12 Science Education* (NRC 2012**)** and *NGSS* (NGSS Lead States 2013).

For school or district administrators, study implications include the following:

- *Encourage or set expectations for same-grade teams to work collaboratively on inquiry-based or other reform-based science planning and implementation*. This will encourage or mandate same-grade team participation in PD.
- *Foster greater prioritization of science teaching*. This promotes a culture of favourable attitudes toward science and implementation of reform practices. Such prioritization of science enhances the quality of teachers' inquiry implementation and the amount of time they allot to science teaching.
- *Provide materials and access to training in using the materials*. An understanding that funds available for science should be established. Encourage teachers to participate in reform-based science PD in which training for using materials is provided.

If these supports are not in place, administrators should carefully consider whether a PD investment will pay off in terms of sustained teacher learning, and ultimately in enhanced student science achievement. Thus, they should consider when to encourage or even mandate teacher participation in a science PD programme. In addition to the implications summarized, we encourage consideration of the following questions: are the potential gains from a programme worth the investment of teacher time and funds? Is the programme of sufficient duration to promote changes in teachers' beliefs and practices? For district administrators, what supports are in place or could be initiated to facilitate school leaders' prioritization of science teaching and support for same-grade team collaboration?

For PD providers, study implications include the following:

- *Focus on providing a comprehensive understanding of new strategies.* If the programme uses the 5E instructional model, for example, it is important to focus time and resources on each of the five elements. Without such an understanding, teachers may only implement selected aspects of an inquiry-based lesson. For a programme aligned with the *Framework* and *NGSS*, this would translate to focusing on a comprehensive understanding of the science and engineering practices and the crosscutting concepts, in addition to disciplinary core ideas.
- *Recognize that belief and practice change take time*. Teachers must be supported and encouraged as they are experiencing change in order to undergo significant transformations in their beliefs about teaching and learning, and in their practices. Different teachers will be ready and willing to make changes at different paces.

- *Provide materials and supplies, and training in their use*. Teachers must have relevant science materials easily accessible, and training in their use, in order to implement new teaching approaches.
- *Offer a support structure for same-grade teams*. Grade-level support appears to be more important than cross-grade support. PD providers should encourage same-grade teams from each school to participate together in PD.
- (*When funds are limited) Select schools to participate based on administrative support for science as a subject and school features such as same-grade collaboration and support, or the potential for such collegial support*. This type of selectivity will provide a greater opportunity for the investment in science PD to pay off and be successful. Further, PD programmes can provide education for principals about how to maintain the reform-based changes after a programme ends.

If funding and personnel are not available to provide these resources and supports, PD providers should carefully consider whether the plan for a science-based PD programme will be effective. If not, it may not be worth the investment of teachers' and PD providers' time as well as the funds required to hold the programme.

For funders, when considering which programmes to fund, the funders need to take into consideration the implications outlined for administrators and PD providers. Programmes that include these features and supports will have an increased likelihood of leading to sustained teacher learning and increased student achievement. If these elements are not in place, the programme may be a poor investment.

In conclusion, the study findings inform the science education, policy, organizational and PD literature bases about the types of supports and resources teachers require in the school context in order to maintain or build on PD experiences. The study results speak to the need for leaders to support science teachers in their learning and change process to meet the goals of current science education reforms.

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Appendix 1. Quantitative data results

Inquiry practice: The analysis of variance results from the RTOP instrument that measured inquiry practice revealed statistically significant increases in practice during the two years, Wilks' $\Delta = 0.24$, $F(4,8) = 6.21$, $p = 0.01$, partial $\eta^2 = 0.76$. Pairwise comparisons indicated no significant differences in any time period other than autumn to winter in year 1. Follow-up polynomial contrasts indicated a significant linear effect with means increasing over time across the two years, $F(1, 11) = 27.4$, $p < 0.001$, partial $\eta^2 = 0.71$. Teachers' scores rose over the two years, although at a slower rate after winter of year 1, and evening out between autumn and spring of year 2.

Beliefs about teaching and learning: Quantitative results from the BARSTL instrument, which measured teachers' beliefs about teaching and learning through inquiry, revealed statistically significant increases over the two years, Wilks' $\Delta = 0.24$, $F(2,10) = 16.21$, $p < 0.001$, partial $\eta^2 = 0.76$. While pairwise comparisons indicated significant increases in year 1, no significant increases were found in year 2. Follow-up polynomial contrasts showed a significant linear effect with means increasing over time during the two years, $F(1, 11) = 27.4$, $p < 0.01$, partial $\eta^2 = 0.72$, indicating that scores continued to increase in year 2, although at a lesser rate. So, teachers increased in their inquiry-based beliefs over both years but the rate was lower in the year following program participation.

Content knowledge: Results revealed statistically significant increases in content knowledge over the two years, Wilks' $\Delta = 0.21$, $F(2,10) = 18.64$, $p < 0.01$, partial $\eta^2 = 0.79$. *Post-hoc* pairwise tests revealed that teachers' content knowledge scores increased significantly in both year 1, $t(14) = 2.41$, $p = 0.03$, and year 2, $t(11) = 2.45$, $p < 0.03$. A Wilcoxon non-parametric test confirmed this finding, showing a significant increase in content knowledge scores during years 1 and 2 at the $\alpha = 0.05$ level. See Figure 1 for changes in all three measures across years 1 and 2.

The following are the means and standard deviation results for each instrument. Significance is noted from the previous data collection period.

Instrument	Autumn year 1	Winter year 1	Spring year 1	Autumn year 2	Spring year 2
RTOP	M = 28.75 SD = 18.70	M = 45.25*** SD = 18.12	M = 49.13 SD = 15.01	M = 51.33 SD = 18.1	M = 51.10 SD = 13.0
BARSTL	M = 66.73 SD = 5.17	N/A	M = 71.4** SD = 4.65	M = 72.5 SD = 4.54	M = 73.6 SD = 6.58
MOSART	M = 0.66 SD = 0.18	N/A	M = 0.73* SD = 0.16	M = 0.75 SD = 0.17	M = 0.81* SD = 0.14

Notes: M = mean; SD = standard deviation.*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.