J Sci Teacher Educ (2015) 26:471–496
DOI 10.1007/s10972-015-9433-4

Understanding Inservice Science Teachers' Needs for Professional Development

Meilan Zhang[1] · Joyce Parker[2,3] · Matthew J. Koehler[2] · Jan Eberhardt[3]

Published online: 31 May 2015

Abstract Prior research has mainly focused on what makes professional development effective from the program design perspective. However, there is a lack of understanding about what teachers need for improvement in the context of educational reforms and curricular changes. This study used the pedagogical content knowledge framework to examine teachers' needs for professional development situated in specific science topics. Data were drawn from a total of 118 science teachers who participated in a professional development program over 3 years. First, this study identified a list of common science topics that teachers needed to improve in life science, physics science, and earth science. Also, teachers perceived the needs to improve teaching of certain topics for different reasons: themselves, students, and curricular changes. Moreover, data analysis showed that teachers needed improvement in multiple areas of pedagogical content knowledge: learners, instructional strategies, curriculum, and assessment. In particular, inquiry teaching was one of the greatest challenges for most teachers.

Keywords Teacher professional development · Inservice science teachers · Needs assessment · Teacher learning · Pedagogical content knowledge

✉ Meilan Zhang
mzhang2@utep.edu

[1] College of Education, University of Texas at El Paso, EDUC 801D, 500 W. University Ave., El Paso, TX 79968, USA

[2] College of Education, Michigan State University, East Lansing, MI, USA

[3] College of Natural Science, Michigan State University, East Lansing, MI, USA

Introduction

There is little argument that teachers hold the key for the success of educational reforms. Research shows that teacher effectiveness is a strong predictor of student academic achievement (Wright, Horn, & Sanders, 1997). The recognition that teachers are at the heart of educational reforms led policy makers and national standards to demand high-quality professional development (PD) opportunities for teachers. To improve teacher quality, each year the US federal government, states, and school districts invest billions of dollars in PD for inservice teachers. Unfortunately, the results of PD efforts have been largely disappointing. Too often, teachers find PD irrelevant to their work in classrooms and misaligned with their needs for improvement (Borko, 2004; Rotherham, Mikuta, & Freeland, 2008). Lieberman and Mace (2008) criticized that “Professional development, though well intentioned, is often perceived by teachers as fragmented, disconnected, and irrelevant to the real problems of classroom practice” (p. 226).

A fundamental problem of traditional PD is that it fails to address teachers’ needs (Borko, 2004; Rotherham et al., 2008). Thus, researchers call for PD programs to be responsive to teachers’ needs for improving their practice. For example, Rotherham et al. (2008) urged that “To strengthen professional development, the federal government should draw on examples of well-tailored professional development programs based on teachers’ needs” (p. 248). Therefore, more research is needed to understand the needs of science teachers for improvement.

To fill the gap, this study aimed to examine teachers’ needs for PD. The context of this study was a PD program for science teachers. To clarify, teachers’ actual experience in the PD, while undoubtedly important, was beyond the scope of this study. To tailor our PD to teachers’ needs, we asked teachers to choose two science topics in their teaching that they felt were in great need for improvement. Teachers were also asked to identify specific areas they hoped to improve in the two units. It should be noted that teachers are situated in an ecological teaching system and have to navigate through multiple demands posed by the school, community, district, state, and national requirements and policies (Zhao & Frank, 2003). Therefore, what teachers perceive to need improvement may be a reflection of external requirements, rather than their own internal needs. Nonetheless, teachers’ self-perceived needs can still provide valuable insights into the priorities and challenges in science teaching, considering the central role of teachers in the ecological teaching system (Zhao & Frank, 2003). The following research questions guided this study.

1. What science topics were perceived to need improvement by K-12 inservice science teachers and why?
2. What aspects of knowledge did inservice science teachers need to improve for the selected science topics?
3. How did teachers’ needs vary depending on teacher backgrounds including teaching experience, grade-level, and gender?

Hewson (2007) argued that there are two essential focal points for discussing PD for science teachers: programs and teachers. On one hand, from the perspective of program design, there is a growing body of literature on characteristics of effective (or high quality) PD. On the other hand, from the focal point of teachers, a significant body of literature has examined what teachers need to know and should be able to do in the climate of educational reforms. In theory, it makes sense that these two lines of research should go hand in hand—effective PD should teach teachers what they need to know and help them deal with challenges arisen from practice. However, research on effective PD is largely disconnected from research on teacher knowledge. We argued that understanding of teacher knowledge provides a useful framework for considering teachers' needs for PD, which serves as a basis for designing effective PD. The following section provides an overview of the two bodies of research.

Literature Review

What Makes PD Effective?

Recent research has yielded important insight on what makes PD effective. Garet, Porter, Desimone, Birman, and Yoon (2001) analyzed survey data from a national sample of 1027 math and science teachers who participated in the Eisenhower PD Program. The researchers found three structural features that helped to set a positive context for a PD activity to take place, including extended study time, collective participation, and emphasis on reform-oriented activities (e.g., study group, mentoring) rather than traditional activities (e.g., workshop). In addition, the authors identified three core features of PD activities that could enhance teacher learning and improve classroom practice, including focus on subject content knowledge, opportunities for active learning (e.g., observing other teachers or being observed), and coherence with teachers' other PD experiences and state and district standards.

Penuel, Fishman, Yamaguchi, and Gallagher (2007) examined the effectiveness of characteristics of PD in fostering curriculum implementation using a sample of 454 science teacher participants. Their findings were largely consistent with what Garet et al. found. In particular, this study highlighted the importance of coherence of PD, defined as "teachers' interpretations of how well aligned the PD activities are with their own goals for learning and their goals for students" (p. 931). Among all the variables studied using hierarchical linear modeling, coherence was the strongest positive predictor for change in teacher knowledge and classroom practice. Coherence was also found to have a positive impact on curriculum implementation. This study provided strong evidence that PD should be responsive to teachers' needs.

In addition, several large-scale studies on the Local Systemic Change (LSC) through Teacher Enhancement Initiative shed some light on features in high-quality PD (Banilower, Heck, & Weiss, 2007; Supovitz & Turner, 2000). The goal of LSC was to improve teaching of science, mathematics, and technology through teacher PD, with a focus on preparing teachers to implement designated exemplary curriculum materials. These studies emphasized that effective PD should be content-based, situated in classroom practice, and sustained over time.

Taken together, there is a broad consensus that effective PD should include the following features: (1) informed by learning theories, (2) intensive, sustained and ongoing learning, (3) focus on content and curriculum, (4) opportunities for rich and active learning, (5) collaboration with other teachers, preferably from the same school, (6) connected to teachers' daily practice and their own learning goals, and (7) aligned with local, state, and national standards and objectives (Banilower et al., 2007; Borko, 2004; Borko, Jacobs, & Koellner, 2010; Garet et al., 2001; Loucks-Horsley, Love, Stiles, Mundry, & Hewson, 2003; Penuel et al., 2007; Supovitz & Turner, 2000).

The studies aforementioned made important contribution to the knowledge base of teacher learning and pointed out critical principles for PD design. However, some of these characteristics of high-quality PD are still too broadly defined to provide detailed guidance for PD design. PD should be relevant to teachers' needs and coherent with their goals—a key feature of effective PD. Yet, we know little about what those needs are.

In addition, research on characteristics of effective PD rarely connects explicitly to research on teacher knowledge, although teacher learning is the common subject in both areas of study. To understand teachers' needs for PD, it is important to analyze the task of teaching—what teachers need to know and should be able to do.

What do Teachers Need to Know and Be Able to Do?

A significant body of literature has examined what teachers need to know and should be able to do in the context of educational reforms. In a review of research on science teacher knowledge, Abell (2007) developed a model of teacher knowledge that includes four types of knowledge base: subject content knowledge, pedagogical knowledge, knowledge of context, and pedagogical content knowledge (PCK). Subject content knowledge includes important facts, concepts, principles, theories, and procedures that are interconnected in a science discipline. Much research has shown that deep, structured, and accessible subject content knowledge is necessary for effective science teaching (Kennedy, 1998). Indeed, a teacher cannot effectively teach any topic without solid content understanding. Therefore, in this study, we examined teachers' needs for improving their own content understanding.

Pedagogical knowledge includes general knowledge of teaching and learning, such as learning theories, instructional principles, and classroom management. An important aspect of general pedagogical knowledge is classroom interaction and organization (Morine-Dershimer & Kent, 1999). Knowledge of context represents background knowledge of students, school, community, and district (Grossman, 1990), also referred to as *classroom knowledge* by Barnett and Hodson (2001), which is "entirely situational and particular" and "rooted in the day-to-day experience of particular educational situations" (Barnett & Hodson, 2001, pp. 438–439). In this study, we did not focus on knowledge of context because this type of contextual knowledge is most likely to be gained and accumulated from a teacher's daily interaction with students and local communities, rather than from external PD.

Of particular importance is PCK, which is commonly believed as having the greatest impact on teachers' classroom practice (Gess-Newsome, 1999). Therefore, this study adopted PCK as the theoretical framework to understand teachers' needs for professional development. The notion of PCK was first introduced by Shulman (1986, 1987). According to Shulman (1987), PCK "represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to diverse interests and abilities of learners, and presented for instruction" (p. 8). In addition, a teacher needs to understand what makes a specific topic difficult to learn and know how to build on students' prior knowledge. The hallmark of PCK is knowledge of teaching specific topics to learners, which distinguishes a teacher from a content specialist or a pedagogical generalist.

There is a growing consensus that PCK should be the focus of teacher PD (Bausmith & Barry, 2011; Hashweh, 2013; Van Driel & Berry, 2012). However, few PD programs seem to have focused on the topic-specific nature of teacher knowledge. Yager (2005), for example, criticized that "One of the most serious problems concerning professional development is the fact that schools often plan general workshops with general leaders—all seemingly having little to do with specific curriculum components or day-to-day teaching" (p. 99). Similarly, based on a review of different models of teacher learning and PD, Hashweh (2013) found it surprising that "Research on teacher learning and development…still views teacher learning as a generic activity and neglects the domain or discipline specificity of teacher learning and development" (p. 136).

In order to design PD that focuses on the development of topic-specific PCK, we first need to understand teachers' topic-specific needs for improvement. To fill the gap, in this study we investigated K-12 science teachers' needs for PD with respect to specific science topics that they hoped to improve, rather than asking teachers about their needs for improvement in general. We analyzed teachers' needs according to the PCK framework. Next, we clarify the specific aspects of PCK that this study focused on, given various interpretations of this framework.

Since its introduction, the notion of PCK has stimulated a rich body of research in teacher education and has been interpreted, refined, and extended by numerous researchers (Loughran, Mulhall, & Berry, 2004; Magnusson, Krajcik, & Borko, 1999) (see Hashweh, 2013, for a more comprehensive review on the evolvement of PCK conceptualization over the past 25 years since Shulman introduced the concept). For example, Grossman (1990) added two additional categories to PCK, namely knowledge and beliefs about purposes, and knowledge of curriculum materials. Gudmundsdottir (1995) argued that the value-laden and narrative nature of PCK should also be included in the notion. Magnusson et al. (1999) proposed a PCK model that included five components, namely orientations toward science teaching, knowledge of science curriculum, knowledge of students' understanding of science, knowledge of assessment, and knowledge of instructional strategies for teaching science. The authors argued that "Effective teachers need to develop knowledge with respect to all of the aspects of PCK, and with respect to all of the topics they teach" (p. 115). The model by Magnusson et al. was a broader conceptualization of PCK than its original focus on topic-specific knowledge.

Lee and Luft (2008) analyzed nine different conceptualizations of PCK models. Despite some variances in the categories of knowledge included in the different PCK models, most models agree that PCK involves (1) knowledge of representations and instructional strategies for teaching specific science topics, (2) knowledge of students, including students' prior knowledge, misconception, and ways to connect science to students' real-world experience, (3) knowledge of science curriculum for particular grade levels and science topics, and (4) knowledge of assessment, including what to assess and how to assess. These aspects of teacher knowledge provide a useful framework to consider what teachers need to learn, and in turn what responsive PD should offer. Therefore, this study examined teachers' needs for professional development in line with these four aspects of PCK (instructional strategy, students, curriculum, and assessment).

In addition, the work of teaching is further complicated by the national reform initiatives. Prior research has documented that teachers had great difficulty implementing inquiry-based science teaching as demanded by the national standards (Germann & Aram, 1996; Martens, 1992), considering that many teachers did not experience inquiry-based learning themselves as students and lacked the knowledge, skills, and beliefs needed to teach science as inquiry. Now more than a decade has passed since the publication of reform documents (American Association for the Advancement of Science, 1993; National Research Council, 1996). Great efforts have been made in both teacher preparation and PD programs to prepare teachers for inquiry-based teaching (Crawford, 2007; Lee, Hart, Cuevas, & Enders, 2004; Schneider, Krajcik, & Blumenfeld, 2005). It is unclear where teachers stand now in their needs for improving their ability to teach science as inquiry. Accordingly, this study examined teachers' perceived needs for improving inquiry-based science teaching, a critical instructional strategy for science education.

Teachers' needs for improvement may be associated with their teaching experience, the grade level they teach, and their gender (Davis, Petish, & Smithey, 2006; Lumpe, Czerniak, Haney, & Beltyukova, 2012). For example, beginning teachers may have a stronger need for improving their PCK than more experienced teachers (Davis et al., 2006). Elementary school teachers tend to view teaching as "activities that work" (Appleton, 2006). Such a view may affect their perceived needs for improvement. They may also benefit more from PD in improving their science content knowledge than secondary teachers (Shin et al., 2010). In addition, prior study found that male teachers held a more positive belief about science teaching than female teachers (Lumpe et al., 2012). Therefore, we were interested in whether teachers' needs varied depending on teacher backgrounds such as teaching experience, grade level, and gender.

Methodology

Research Design

This study employed a survey research design to understand teachers' needs for PD. This method allowed us to gain insights into teachers' self-perceived needs for improvement, revolving around the critical aspects of what teachers need to know and do as described in the literature. Prior research suggested that self-report surveys provide a low-cost and relatively accurate portrait of teacher belief and practice (Ross, McDougall, Hogaboam-Gray, & LeSage, 2003). Survey methods have been widely used in research that focused on teachers, such as teachers' perceptions of job satisfaction (Liu & Meyer, 2005), self-efficacy as teachers (Bleicher, 2004), technology integration in classrooms (Proctor & Marks, 2013), and standards-based classroom practice (Ross et al., 2003).

Limitations of the Study

Before we describe the details of participants, data sources, and analysis, several limitations of this study should be noted. First, the teachers in this study were self-selected for participating in the PD. This group of teachers may be more motivated to improve their practice than other teachers. Second, this study reflected teachers' self-reported needs for improvement, which may be different from their actual needs. For example, teachers might believe they had stronger science content knowledge than they actually did. Third, the findings of this study were based on teachers' survey responses only, without triangulation using data from multiple sources and multiple methods such as interviews with teachers or PD facilitators. Finally, the sample size of this study was relatively small. These limitations may affect the generalizability of the findings of this study.

Participants

This study was situated in a PD program hosted by a science education division at a large Midwestern university in the USA. We recruited teachers for the PD in a variety of ways. We mailed the program description brochures and application materials to local schools and distributed them at the school district centers and local science education conferences. In addition, the previous PD participants also helped to recruit peers in their school. Teachers who applied before the deadline were all enrolled to the PD. Participation was voluntary. Participants received a small amount of stipend and continuing education credits as compensations for their effort in the PD.

Participants in this study included a total of 118 K-12 inservice science teachers who voluntarily participated in our PD program over 3 years. One PD cycle, including a 2-week summer workshop and a school-year teacher research project, was completed in 1 year. Some teachers chose to participate again to improve themselves as teachers, as they worked on different content and pedagogical issues in another year. Among the 118 teachers (96 females and 22 males), 84 teachers participated in the project for 1 year, 22 teachers for 2 years, and 12 teachers for 3 years, which resulted in 164 participants over 3 years. Because this study did not focus on the impact of the PD, we treated each participation by the same teacher separately. The teachers were divided into three groups according to years of teaching experience: beginning teachers with 0–3 years of teaching experience; established teachers with 4–10 years of experience, and veteran teachers who had

Table 1 Teacher participants background

	Year 1 ($N = 44$)	Year 2 ($N = 43$)	Year 3 ($N = 77$)
Gender			
Female	33	37	69
Male	11	6	8
Grade			
Elementary (K-6)	30	29	43
Secondary (7–12)	14	14	34
Race			
White	41	41	73
Minorities	3	2	4
Average teaching experience (in years)	8.7	12.4	11.5
Beginning (0–3 years)	16	5	7
Established (4–10 years)	14	13	38
Veteran (>10 years)	14	25	32
Age (in years)	39.3	42.9	39.5

more than 10 years of experience. Also, 62 teachers taught science at the middle and high school levels, and 102 teachers taught science as part of their load at an elementary school. Table 1 describes the teachers' backgrounds.

Data Sources

The PD took place in the summer and the following school year. Teachers submitted their application for the PD from February to March prior to a PD cycle. By the time Cohort 3 teachers applied for the PD, the state implemented a new curriculum standard called the Grade Level Content Expectations (GLCEs), which has now been replaced by the Common Core State Standards.

In the application form, the teachers were asked to select two science unit topics from their teaching, one as the first choice and the other as the second choice, to improve in the PD. The teachers were asked to rate to what extent they thought the selected topics needed improvement in nine aspects on a 5-point Likert scale, with 1 indicating "needs no development" and 5 indicating "needs a lot of development." The nine aspects measured content knowledge (CK), pedagogical knowledge (PK), and PCK, including: (1) my own understanding of big ideas in the subject (CK); (2) my interactions with my students (PK); (3) teaching this unit with inquiry or scientific reasoning (PCK: Strategy); (4) building concepts through a series of activities (PCK: Strategy); (5) my students' grasp of big ideas in the subject (PCK: Learner); (6) addressing students' misconceptions (PCK: Learner); (7) relating unit content to students' lives (PCK: Learner); (8) developing effective assessments (PCK: Assessment); and (9) finding good resource materials on the Internet (PCK: Curriculum).

In addition to the rating scale, for each unit topic, the teachers were asked two open-ended questions: (1) Why have you chosen this unit topic for improvement? and (2) What would you most like to improve? Because teacher responses to these questions were situated in the specific topics that they chose, we considered the areas for which the teachers perceived the needs for improvement to be different aspects of PCK.

Data Analysis

We analyzed the teachers' ratings and provided descriptive statistics on teachers' needs for improvement in the nine areas. We used one-way analysis of variance (ANOVA) and *t* tests to examine whether teachers' needs in their first-choice unit were related to their teaching experience, grade level, and gender.

All teachers' open-ended responses were entered into a spreadsheet and organized by cohorts and units. Analysis of these responses was an iterative process guided by the grounded theory approach (Glaser & Strauss, 1967). Through repeated readings of these responses, the first author developed and refined a coding scheme to categorize teachers' responses based on the PCK framework. The unit of analysis was defined to be a thematic unit in the responses that represented a single idea. This definition was common in content analysis research (Rourke & Anderson, 2004; Strijbos, Martens, Prins, & Jochems, 2006). Teachers might specify one or more areas they wanted to improve for their selected topic in their responses. For example, a high school teacher chose to work on a unit called "organizational living things." Her response to "What would you most like to improve?" was "How to teach this through inquiry? How to make this relevant to the students?" This response was coded as "PCK: Learner: Relevance" and "PCK: Strategy: Inquiry, PBL." The coding scheme was revised in the iterative coding process. For example, at first, inquiry-based learning and problem-based learning (PBL) were considered separate categories under PCK: Strategy. However, it turned out that many teachers did not differentiate the two strategies as they often put them together in their responses. Therefore, it seemed more reasonable to combine the two strategies in one category. Once the coding scheme became stable after numerous revisions, the first author used about 10 % of the data to train another researcher who was not involved in developing the coding scheme. Two researchers coded about 40 % of the data independently, and the inter-rater reliability was 91 %. Disagreement was resolved through discussion. The first author coded the remaining data. Table 2 presents the coding scheme for teachers' open-ended responses.

Results

What Science Topics were Perceived to Need Improvement by Science Teachers and Why?

A total of 230 science topics were selected for improvement by the teachers in three cohorts. Not all teachers selected two topics. Some just selected one. In Table 3,

Table 2 Coding scheme for teachers' needs for improvement

Type of knowledge	Code	Explanation	Example from teacher responses
CK	Content	Improve teachers' content understanding of selected topic	I would like to expand my knowledge of this topic
PCK: learner	Student understanding	Improve or deepen student understanding of selected topic	I would like to improve students understanding of the major concepts of plate tectonics, earthquakes and volcanoes
	Interest	Engage learners; Improve student interests in the topic	I'd like to improve my ability to plan lessons that spark students' interest and engage them in learning
	Relevance	Make science relevant to students; connect to students' real-life experience	I would like to find and learn more ways to make science in general more relevant to the student life
	Age-appropriateness	Design lessons that is age-appropriate or grade-level appropriate	Our first-grade unit needs to be rewritten to make sure it is developmentally appropriate and prepares students for fourth-grade light + color unit
	Differentiation	Differentiate instruction for different learners	I would like to work on Big Idea, as well as a tiering [misc.] differentiated approach to teaching either of these units
	Misconception	Address student misconception in the selected topic	I would like to address student misconceptions in this topic
PCK: strategy	Inquiry/PBL	Use inquiry-based learning or problem-based learning approach	I want to incorporate more inquiry into this unit
	Hands-on activities	Use hands-on activities, laboratories, experiments	I need more hands-on activities/laboratories/experiments
	Representation	Improve presentation of information	More examples, resources, visual aids
	Connection	Make connection between activities and concepts, or between concepts	Student connections between activities and concepts
	Technology	Use technology to enhance teaching	We need time to develop lesson plans using (CBL)/lab pro software we recently acquired through a technology grant
	General	Improve teaching strategy in general	My knowledge of this topic, and how to teach it

Table 2 continued

Type of knowledge	Code	Explanation	Example from teacher responses
PCK: curriculum	Alignment	Align instruction with state and district curriculum standards	I want to make sure this unit is aligned with state standards
	Resources	Need to find more resources or learn to use existing resources, in addition to text book	I need more resources
	Organization	Improve organization of a unit; identify big ideas of a unit; improve lesson flows, sequencing, and continuity between lessons	I want to improve the organization of this unit, the sequence of activities
	Cross-subject	Integrate other subjects into science lessons	Incorporate literacy into science
PCK: assessment	Assessment	Design assessment to evaluate student learning	I would like to improve assessment
	Test outcome	Improve students' performances in standardized tests	Student outcomes on MEAP
Overall	All	All aspects need to improve	We are starting from scratch and would like to create a unit to use in the classroom
	Other	Responses that did not fit the categories above	I want to teach my students problem solving skills outside of math

Table 3 Types of unit topics and areas

Grade level	Life science	Physics science	Earth science
K-2nd	Five senses^{7}, Life cycles^{4}, Plants^{4}, Animals^{3}, Ecosystems^{2}, Organisms^{2}, Organization of living things^{2}, Food chain^{1}, Needs of living things^{1}	Force and motion^{5}, Light and shadow^{3}, Magnets^{3}, Matter^{3}, Sifting through science^{3}, Light and color^{1}, Simple machines^{1}	Rocks^{5}, Weather^{4}, Earth surface^{3}, Geosphere^{2}, How does water move?^{2}, Recycling and trash^{1}
3rd–5th	Ecosystems^{10}, Plants^{3}, Heredity and evolution^{2}, Human body^{2}, Animal classification^{1}, Organisms^{1}, Plant classification^{1}, Scientific method^{1}, Transfer of energy through food chain^{1}	Force and motion^{19}, Matter and energy^{6}, Simple machines^{6}, Light and shadow^{3}, Electricity^{2}, Light and sound^{1}, Newton's Laws^{1}, Sound^{1}	Solar system^{7}, Weather^{6}, The changing Earth^{2}, Geoshpere^{2}, Space^{2}, Astronomy^{1}, Moon cycle^{1}, Planets^{1}, Atmosphere^{1}
6th–8th	Cells^{4}, Ecosystems^{3}, Genetics and heredity^{3}, Plant classification^{2}, Human body^{2}, Plants^{3}, Animals^{1}, Bacteria and viruses^{2}, Protists^{1}	Force and motion^{4}, Matter and energy^{3}, Chemical changes^{1}, Electricity and magnetism^{1}, Light^{1}	Weather^{5}, Rocks and minerals^{3}, Plate tectonics^{2}, The changing Earth^{2}, Geology^{2}, Hydrosphere^{1}, Rock cycle^{1}, Solar system^{1}, Space^{1}, Water cycle^{1}, Weathering and erosion^{1}
9th–12th	Cancer^{2}, Cell^{2}, Ecology^{2}, Geckos^{2}, Human anatomy^{2}, Chemical basis of life^{1}, Energy flow in environment^{1}, Evolution^{1}, Genetics^{1}, Heredity^{1}, Marine bio-structure and class^{1}, Skeleton^{1}, Using vignettes^{1}, Viruses and bacteria^{1}	Force and motion^{4}, Matter and energy^{3}, Chemical changes^{1}, Electricity and magnetism^{1}, Light^{1}	Rocks and minerals^{3}, Global science^{1}

The number in superscript next to the topic represents the total number of teachers who selected the topic

these topics were presented according to science areas (life science, physics science, and earth science) and grade levels.

Specifically, in life science, ecosystems, plants and animals, and human body were some common topics across grade levels. In addition, in Grades K-2, five senses and life cycles were common science topics for improvement. In secondary grades, cells, genetics and heredity, and bacteria were common topics. In physics, force and motion was the most common topic across grade levels. In addition, matter and energy and light and shadow were also common topics that the teachers selected for improvement in all grade levels. In earth science, rocks and minerals, weather, solar system, and the changing Earth were common topics mentioned by the teachers across grade levels.

There were four major reasons that the teachers explained when asked why they chose certain unit topic for improvement. First, about 23 % of teachers reported that the selected topic was their weak area due to a lack of content knowledge, training, or interest. It was not uncommon that teachers had to teach outside of their field. Examples of the teachers' responses were as follows: "This is an area [force and motion] that I know the least about. I would like to capture students' attention in this area;" "I feel this is an area [solar system] in which I do not have as much background knowledge in. Most of my undergraduate work was focused on the life sciences," and "Being a biologist, I am not as interested in this area of study [weather]. I need to build my interest in order to inspire the interest of my students."

Second, the teachers selected a science topic to work on because the topic was too difficult for students to learn, or because it was an important topic. About 10 % of teachers indicated that their selected topic was too complicated and abstract, which cannot be seen and students tended to have misconceptions. Examples included: "I have chosen this unit [ecosystems] because many of my students have a difficult time placing animals in the correct [habitat], thus making it hard for them to make correct choices when making a food chain." "Both of these units [weather or rocks and minerals] are conceptually difficult for 11- to 12-year-old students. Students love the laboratories but don't see the connection with the concepts," and "I would like to improve our unit on protists because they are confusing to the students and easy to get mixed up." In addition, about 5 % of teachers indicated that they selected a topic because it was important or appealing to students, for example, "Kindergarten children have high interest in this topic [magnets]," and "I chose this topic because the advanced rock cycle is a major concept in the new HSCE [High School Content Expectations] for earth science. It is also related to many other topics such as plate tectonics and the formation of geologic features."

Third, the most common reason was that the teachers hoped to refine an existing unit to engage students and improve understanding. About 38 % of the teachers' explanations fell into this category, for example, "I have chosen this unit topic [energy and its transformations] as I don't feel I necessarily give students good concrete examples of everyday energy changes," and "I've been teaching it [ecology] the same way for so long; I want new ideas for investigations." In particular, many teachers mentioned that they wanted to improve the unit by using inquiry-based or problem-based approach, for example, "I want the genetics unit in my biology class to be more hands-on and inquiry-based."

Finally, 24 % of teachers, most from the last cohort, reported that they chose a topic because it was a new unit that they needed to develop to align with the new GLCEs that were implemented in the state during that year. The teachers often mentioned that they had to start from scratch and asked for help, for example, "We have new K-level GLCEs for this area and I don't know where to begin!" and "A big section of the GLCEs focus on this [force and motion] and I do not have a lot of knowledge about this information."

What Aspects of Knowledge did Inservice Science Teachers Need to Improve for the Selected Science Topics?

Analysis of Teachers' Ratings

The descriptive statistics for teachers' needs for improvement based on their ratings are presented in Table 4. First, teaching a unit with inquiry or scientific reasoning was the most needed area for improvement for the teachers. For both units, there were about 80 % of teachers who rated 4 or 5 on the 5-point Likert scale, indicating that most teachers believed that they needed substantial improvement in this area.

The other three areas that the teachers identified as needing significant improvement were fostering conceptual understanding, building concepts through activities, and developing effective assessment. In addition, over half of the teachers reported that they needed considerable improvement in addressing students' misconceptions, finding resources on the Internet, and connecting unit content to students' lives.

On the other hand, the teachers were confident in their interactions with students and they rarely mentioned their needs for improvement in this aspect in their open-

Table 4 Descriptive statistics for teachers' needs for improvement from rating-scale questions

	First-choice unit				Second-choice unit			
	N	Mean	SD	4/5* (%)	*N*	Mean	SD	4/5* (%)
Teaching this unit with inquiry or scientific reasoning (PCK: strategy)	161	4.10	0.86	79	144	4.06	0.78	80
My students' grasp of big ideas in the subject (PCK: learner)	155	3.90	0.77	72	142	3.92	0.78	74
Building concepts through a series of activities (PCK: strategy)	161	3.86	0.91	70	144	3.88	0.88	71
Developing effective assessments (PCK: assessment)	159	3.82	0.94	68	143	3.86	0.87	72
Addressing students' misconceptions (PCK: learner)	159	3.74	0.88	59	143	3.81	0.83	63
Finding good resource materials on the Internet (PCK: curriculum)	159	3.69	1.00	59	143	3.61	0.93	55
Relating unit content to students' lives (PCK: learner)	118	3.58	0.94	57	103	3.72	0.86	65
My own understanding of big ideas in the subject (CK)	160	3.07	1.07	34	143	2.97	1.08	29
My interactions with my students (PK)	157	2.76	0.99	24	142	2.70	0.95	20

On the 5-point Likert scale, 1 = "Needs no development"; 5 = "Needs a lot of development"

There were missing responses for certain questions, so the "*N*" was different

CK = content knowledge, PK = pedagogical knowledge, PCK = pedagogical content knowledge

* 4/5 Percentage of teachers who rated 4 or 5 on the item

ended responses. The teachers were also relatively confident in their own understanding of big ideas in the subject, indicated by the low mean scores of 3.07 and 2.97 in the two unit choices, respectively, which were the second lowest rating in both units.

Overall, the teachers' needs for improvement in different areas were fairly consistent in the first-choice unit and the second-choice unit. Paired sample t tests found none of the mean differences between the two units in the same area were statistically different.

Analysis of Teachers' Open-Ended Responses

When asked what they would most like to improve in the two unit topics they selected, the teachers indicated their needs for improving their content knowledge and PCK in four aspects: learners, instructional strategies, curriculum, and assessment. Table 5 presents the frequency count and percentage of teachers who indicated their needs for improvement in each aspect.

Table 5 Teachers' needs for improvement from open-ended responses

Type of knowledge	Code	Cohort 1 ($n = 44$)	Cohort 2 ($n = 43$)	Cohort 3 ($n = 77$)	Total ($n = 164$)
CK	Content	17 (39 %)	19 (44 %)	50 (65 %)	86 (52 %)
PCK: learner	Student understanding	18 (41 %)	6 (14 %)	31 (40 %)	55 (34 %)
	Interest	12 (27 %)	17 (40 %)	23 (30 %)	52 (32 %)
	Relevance	10 (23 %)	9 (21 %)	17 (22 %)	36 (22 %)
	Age-appropriateness	4 (9 %)	3 (7 %)	5 (6 %)	12 (7 %)
	Differentiation	4 (9 %)	0 (0 %)	2 (3 %)	6 (4 %)
	Misconception	1 (2 %)	1 (2 %)	1 (1 %)	3 (2 %)
PCK: strategy	Inquiry/PBL	21 (48 %)	15 (35 %)	47 (61 %)	83 (51 %)
	Hands-on activities	23 (52 %)	14 (33 %)	31 (40 %)	68 (41 %)
	Representation	5 (11 %)	3 (7 %)	7 (9 %)	15 (9 %)
	Connection	4 (9 %)	0 (0 %)	5 (6 %)	9 (5 %)
	Technology	4 (9 %)	2 (5 %)	0 (0 %)	6 (4 %)
	General	1 (2 %)	6 (14 %)	8 (10 %)	15 (9 %)
PCK: curriculum	Alignment	12 (27 %)	10 (23 %)	62 (81 %)	84 (51 %)
	Resources	14 (32 %)	10 (23 %)	8 (10 %)	32 (20 %)
	Organization	6 (14 %)	11 (26 %)	9 (12 %)	26 (16 %)
	Cross-subject	2 (5 %)	1 (2 %)	0 (0 %)	3 (2 %)
PCK: assessment	Assessment	5 (11 %)	5 (12 %)	15 (19 %)	25 (15 %)
	Test outcome	3 (7 %)	2 (5 %)	3 (4 %)	8 (5 %)
Overall	All	2 (5 %)	4 (9 %)	15 (19 %)	21 (13 %)
	Other	3 (7 %)	2 (5 %)	6 (8 %)	11 (7 %)
Total		171	140	345	656

Content Knowledge Although the teachers' average rating for their needs for improving "My own understanding of big ideas in the subject" was only 3.07 out of 5 on the Likert scale question, in the open-ended responses, a considerable percentage of teachers said they needed to improve their own content understanding about the science topics they selected. Overall, 52 % of teachers explicitly mentioned their needs for improving their content understanding. In particular, 65 % of teachers in Cohort 3 reported this need. For example, one fifth-grade teacher in Cohort 3 stated: "Even though I have taught this topic [atmosphere], there are many things I don't truly understand. I feel uncomfortable with much of the content." One possible explanation for the gap between the ratings and open-ended responses was that the teachers might believe they had a good understanding of "big ideas" in the subject, but lacked an in-depth content understanding.

PCK: Learners The most frequently mentioned needs were improving students' content understanding and making science engaging and relevant to students by connecting science to real life. In fact, all other needs that the teachers expressed were intended to serve these goals, a finding elaborated later. Some teachers also reported needs for designing age-appropriate lessons, differentiating instruction for different learners, and addressing student misconceptions.

PCK: Instructional Strategies Consistent with the teachers' ratings, inquiry teaching was among the greatest needs for improvement reported by the teachers in the open-ended responses. For example, a middle school teacher in Cohort 1 stated, "I find this topic [genetics/heredity] difficult to teach using problem-based/inquiry-based, and I'd like to do a better job of this." Because the PD project used the problem-based learning approach for teacher learning, about half (83) teachers became interested in using problem-based learning for their students. It seems that the teachers did not differentiate inquiry-based learning from problem-based learning, as they often mentioned the two approaches simultaneously. Another frequently mentioned need was to find hands-on activities to engage students, a need reported by 68 teachers. Fifteen teachers wanted to find better ways to represent the science topic, and nine teachers wanted to help students make better connection between activities and concepts. Six teachers wanted to incorporate technology in science teaching. Fifteen teachers indicated that they needed to improve their pedagogy in teaching the science unit in general.

PCK: Curriculum The greatest need that the teachers reported in this category was aligning their teaching with state and district curriculum standards, particularly in the last cohort due to the implementation of new state curriculum standards. The teachers also needed to find more resources or learn to use existing resources to improve their science units. Some teachers had to teach without a textbook. In addition, the teachers needed to improve the organization of a unit, focus on big ideas, and improve lesson flow and sequencing between lessons. A few teachers also wanted to integrate literacy and mathematics into science lessons.

PCK: Assessment The teachers reported needs for designing assessment to evaluate student learning and improving student performances in standardized tests. For example, a teacher in Cohort 3 stated, "I would like to see my team work on assessments for this unit. If we work on the assessment piece, the content and lessons will fall into place."

Also, 21 teachers, with 15 from the last cohort, indicated that they needed improvement in all areas. For example, two teachers in Cohort 3 commented, "This [ecosystems] is a new topic for us. We are starting from scratch and need everything!" and "I have not taught this unit [matter and energy] before, so everything will need development and improvement."

Relationships Between Different Needs

It is also important to note the relationships between different needs. It appears that the teachers ultimately wanted to achieve two goals: improvement in student interest and content understanding. Other needs, such as improving teachers' own content knowledge, use of inquiry or hands-on activities, use of good resources, or better ways of representation, were all means to achieve these goals. The following teacher responses reflected the relationship.

> I hope that the benefit of this professional development would be to increase student interest thereby increase student learning. If student interest and learning is increased then I am being fully fed as a teacher. [10th grade teacher in Cohort 1]
>
> More hands-on activities, to really help engage my students and increase their understanding. [Kindergarten teacher in Cohort 2]
>
> I have not taught force and motion for many years. I'm looking for good problem/inquiry-based lessons to increase the depth of student understanding and allow the students to enjoy the lesson. [6th grade teacher in Cohort 3]

How did Teachers' Needs Vary Depending on Teacher Backgrounds?

We examined the relationship between teaching experience, grade level, and gender and teachers' needs for improvement using ANOVA and *t* tests.

Teaching Experience

The descriptive statistics of teachers' needs for improvement by teaching experience are presented in Table 6. A one-way between-subjects ANOVA was conducted to compare the needs of teachers with different levels of experience. As shown in Table 7, there was a significant effect of teaching experience on teachers' needs for improvement in four aspects: *my own understanding of big ideas in the subject* [$F(2, 157) = 3.442$, $p = .034$]; *teaching this unit with inquiry or scientific reasoning* [$F(2, 158) = 5.133$, $p = .007$]; *relating unit content to students' lives* [$F(2, 115) = 5.025$, $p = .008$]; and *addressing students' misconceptions* [$F(2, 156) = 5.267$, $p = .006$]. As shown in Table 8, post hoc comparisons using the

Table 6 Descriptive statistics of teachers' needs for improvement by teaching experience

	N	Mean	SD	SE
My own understanding of big ideas in the subject				
0–3 years	23	2.96	1.107	0.231
4–10 years	60	3.03	1.057	0.136
>10 years	60	2.9	1.115	0.144
Total	143	2.97	1.084	0.091
My students' grasp of big ideas in the subject				
0–3 years	24	3.96	0.806	0.165
4–10 years	58	3.86	0.687	0.09
>10 years	60	3.97	0.863	0.111
Total	142	3.92	0.782	0.066
My interactions with my students				
0–3 years	24	2.79	0.779	0.159
4–10 years	58	2.79	0.987	0.13
>10 years	60	2.57	0.981	0.127
Total	142	2.7	0.953	0.08
Teaching this unit with inquiry or scientific reasoning				
0–3 years	24	4.17	0.868	0.177
4–10 years	60	4.07	0.71	0.092
>10 years	60	4.02	0.813	0.105
Total	144	4.06	0.777	0.065
Relating unit content to students' lives				
0–3 years	9	3.89	0.928	0.309
4–10 years	47	3.82	0.804	0.117
>10 years	47	3.6	0.901	0.131
Total	103	3.72	0.86	0.085
Addressing students' misconceptions				
0–3 years	24	4	0.834	0.17
4–10 years	59	3.89	0.826	0.107
>10 years	60	3.65	0.82	0.106
Total	143	3.81	0.831	0.069
Developing effective assessments				
0–3 years	23	3.91	0.9	0.188
4–10 years	60	3.82	0.833	0.108
>10 years	60	3.89	0.898	0.116
Total	143	3.86	0.866	0.072
Finding good resource materials on the Internet				
0–3 years	23	3.74	0.864	0.18
4–10 years	60	3.38	0.99	0.128
>10 years	60	3.8	0.86	0.111
Total	143	3.61	0.933	0.078

Table 6 continued

	N	Mean	SD	SE
Building concepts through a series of activities				
0–3 years	24	4.04	0.751	0.153
4–10 years	60	3.87	0.853	0.11
>10 years	60	3.82	0.965	0.125
Total	144	3.88	0.884	0.074

Table 7 One-way ANOVA of teachers' needs for improvement by teaching experience

	Sum of squares	*df*	Mean square	*F*	Sig.
My own understanding of big ideas in the subject					
Between groups	7.684	2	3.842	3.442	.034*
Within groups	175.239	157	1.116		
Total	182.923	159			
Teaching this unit with inquiry or scientific reasoning					
Between groups	7.233	2	3.616	5.133	.007**
Within groups	111.326	158	.705		
Total	118.559	160			
Relating unit content to students' lives					
Between groups	8.316	2	4.158	5.025	.008**
Within groups	95.169	115	.828		
Total	103.485	117			
Addressing students' misconceptions					
Between groups	7.744	2	3.872	5.267	.006**
Within groups	114.684	156	.735		
Total	122.428	158			

* $p < .05$; ** $p < .01$

Tukey HSD test indicated that veteran teachers with more than 10 years of teaching experience were more confident in *teaching this unit with inquiry or scientific reasoning* and *addressing students' misconceptions* than beginning teachers and established teachers with 4–10 years of experience. Also, veteran teachers were more confident in *relating unit content to students' lives* than established teachers.

Grade Level

The descriptive statistics of teachers' needs for improvement by grade level are presented in Table 9. An independent-sample *t* test was conducted to compare the needs of elementary and secondary teachers. As shown in Table 10, *t* test results showed that the elementary teachers who taught Grades K-6 reported greater needs for *improving their own content understanding*, *developing effective assessments*,

Table 8 Post hoc comparisons of teachers' needs for improvement by teaching experience

Dependent variable	(I) Teaching experience (years)	(J) Teaching experience (years)	Mean difference (I − J)	SE	Sig.
My own understanding of big ideas in the subject	0–3	4–10	−.521	.242	.083
		>10	−.113	.240	.885
	4–10	0–3	.521	.242	.083
		>10	.408	.183	.070
	>10	0–3	.113	.240	.885
		4–10	−.408	.183	.070
Teaching this unit with inquiry or scientific reasoning	0–3	4–10	.181	.193	.617
		>10	.536	.190	.015*
	4–10	0–3	−.181	.193	.617
		>10	.355	.145	.041*
	>10	0–3	−.536	.190	.015*
		4–10	−.355	.145	.041*
Relating unit content to students' lives	0–3	4–10	−.557	.292	.142
		>10	−.024	.289	.996
	4–10	0–3	.557	.292	.142
		>10	.533	.177	.009**
	>10	0–3	.024	.289	.996
		4–10	−.533	.177	.009**
Addressing students' misconceptions	0–3	4–10	.150	.200	.735
		>10	.538	.197	.019*
	4–10	0–3	−.150	.200	.735
		>10	.389	.149	.027*
	>10	0–3	−.538	.197	.019*
		4–10	−.389	.149	.027*

* $p < .05$; ** $p < .01$

and *finding good resource materials on the Internet* than the secondary teachers who taught Grades 7–12. On the other hand, elementary teachers were marginally more confident in *teaching this unit with inquiry or scientific reasoning*.

Gender

No significant difference was found between male and female teachers in any of the nine aspects of teachers' needs for improvement.

Discussion

Prior research has mainly focused on what makes PD effective from the program design perspective (Garet et al., 2001; Penuel et al., 2007), while there is a lack of understanding about what teachers need for improvement in the climate of

Table 9 Descriptive statistics of teachers' needs for improvement by grade level

	Grade level	*N*	Mean	SD	SE mean
My own understanding of big ideas in the subject	K-6	99	3.23	1.084	0.109
	7-12	61	2.82	1.013	0.13
My students' grasp of big ideas in the subject	K-6	96	3.94	0.751	0.077
	7-12	59	3.85	0.805	0.105
My interactions with my students	K-6	97	2.79	1.05	0.107
	7-12	60	2.7	0.889	0.115
Teaching this unit with inquiry or scientific reasoning	K-6	100	4.01	0.911	0.091
	7-12	61	4.26	0.751	0.096
Relating unit content to students' lives	K-6	71	3.52	1.026	0.122
	7-12	47	3.67	0.796	0.116
Addressing students' misconceptions	K-6	99	3.83	0.904	0.091
	7-12	60	3.6	0.827	0.107
Developing effective assessments	K-6	100	4.01	0.893	0.089
	7-12	59	3.51	0.935	0.122
Finding good resource materials on the Internet	K-6	99	3.82	0.983	0.099
	7-12	60	3.47	0.999	0.129
Building concepts through a series of activities	K-6	100	3.86	0.888	0.089
	7-12	61	3.87	0.939	0.12

Table 10 *t*-test results for difference between elementary and secondary teachers' needs for improvement

	t	*df*	Sig. (2-tailed)	Mean difference	SE difference
My own understanding of big ideas in the subject	2.368	158	0.019*	0.408	0.172
Teaching this unit with inquiry or scientific reasoning	−1.854	159	0.066	−0.257	0.139
Developing effective assessments	3.361	157	0.001**	0.502	0.149
Finding good resource materials on the internet	2.172	157	0.031*	0.352	0.162

* $p < .05$; ** $p < .01$

educational reforms and curricular changes. This study used the PCK framework to examine teachers' needs for PD situated in specific science topics.

First, this study identified a list of common science topics that teachers needed to improve in life science, physics science, and earth science. For example, both elementary and secondary teachers reported that they needed improvement in teaching ecosystems, human body, and cells in life sciences, and force and motion and matter and energy in physics science. These topics are also among the disciplinary core ideas emphasized in the Next Generation Science Standards (National Research Council, 2013). It is important to note that even some of the experienced teachers with over 10 years of experience still perceived some of these topics difficult to teach. For example, one high school teacher in Cohort 3 with 14 years of teaching experience hoped to improve his teaching of energy because “I don’t feel I necessarily give students good concrete examples of everyday energy changes.” Prior research suggested that in general teachers grow their PCK with more experience (Friedrichsen et al., 2009; Schneider & Plasman, 2011). However, this study showed that it cannot be assumed that the growth will happen in all science topics.

Second, this study further showed that teachers felt the needs to improve teaching of certain topics for different reasons: themselves, students, and curricular changes. The topic might be teachers’ own weak area due to a lack of training and interest. The topic might be too abstract or complicated for students to understand. Also, when new curriculum was implemented, many teachers had to design new units to address the change. Opfer and Pedder (2011) argued that teacher professional learning should be conceptualized to reflect “the complex teaching and learning environments in which teachers live” (p. 377). Consistent with this view, this study suggested that teachers’ needs for improvement were shaped by a complex teaching system that involved both microcontexts (e.g., teachers, students) and macrocontexts (e.g., district- or state-level policy changes in curriculum and assessment). This finding deepened our understanding of the complexity in teachers’ needs for improvement.

Third, this study found that teachers needed improvement in various aspects of PCK: learners, instructional strategies, curriculum, and assessment. In a review of over 100 empirical studies on the challenges facing new science teachers, Davis et al. (2006) found that the vast majority of the studies focused on preservice teachers, with only a few looking at early-career teachers. Research on mid-career and experienced teachers’ needs for improvement is also limited. This study contributed to the literature by examining the needs of beginning, mid-career, and experienced inservice science teachers. In addition, few studies have systematically analyzed teachers’ needs for improvement using the PCK framework. This study enhanced understanding of what inservice teachers needed to improve, what needs were more common than others, and what the relationship among needs was. For example, most teachers ultimately wanted to improve student content understanding and engage students in learning. Other needs intended to help to achieve these goals.

This study found that inquiry teaching was one of the greatest challenges for most teachers. Teaching science as inquiry has been advocated for over a decade (National Research Council, 1996) and is emphasized in the Next Generation Science Standards (National Research Council, 2013). Teacher preparation and professional development programs have invested great effort to help teachers understand and use inquiry teaching (Oliveira, 2010; Schneider & Plasman, 2011). However, inquiry teaching remains difficult to most teachers. Although well-prepared beginning teachers were able to implement inquiry-based science instruction in their first year of teaching (Avraamidou & Zembal-Saul, 2010), this study suggested that for most teachers, including experienced teachers, inquiry teaching was still their greatest challenge (see Tables 5, 6) and required significant support from PD programs. This finding is consistent with previous research that documented the challenges of inquiry teaching (Crawford, 2007; Johnson, 2006; Wee, Shepardson, Fast, & Harbor, 2007).

Moreover, teachers' needs may be affected by their teaching experience and the level they teach. Beginning teachers and elementary teachers reported greater needs for improvement in content, learner, curriculum, and assessment than did experienced and secondary teachers. This finding provided additional evidence to the particular challenges facing beginning elementary teachers. In their review, Davis et al. (2006) found that mixed results were reported on preservice secondary teachers concerning their content knowledge, but "in almost all of the studies reviewed here, the [preservice elementary] teachers were found to have unsophisticated understandings of science" (p. 614). Our study suggested that similar differences remained between inservice elementary and secondary teachers.

In particular, the Cohort 3 teachers reported greater needs for improving their own content understanding and student understanding, using inquiry-based approaches, and aligning with standards due to the implementation of new state curriculum standards. For example, 81 % of teachers in Cohort 3 reported that they needed to improve their units to better align with the standards, compared to only 27 and 23 % in the previous two cohorts, respectively. A sizable number of Cohort 3 teachers reported that they had to design a new unit from scratch and had to teach unfamiliar topics, which made them frustrated and anxious. In fact, the number of participants in the last cohort increased dramatically from the first 2 years, mainly due to the change of curriculum standards. This finding reinforced the importance of PD support in helping teachers to adapt to curricular changes (Jones & Eick, 2007).

Implications of the Study

Effective PD that aims to improve teachers' classroom practice should be aligned with teachers' needs. If the areas that teachers need to improve can be clearly identified, then it will be easier to develop responsive PD programs to address these needs. Thus, the findings of this study have important implications for educational researchers, teacher educators, and PD providers by pointing out promising directions to invest their valuable time and resources. First, PD designers should target the common topics that many teachers find difficult to teach, such as ecosystems and force and motion. Second, many teachers in this study perceived inquiry teaching to be the greatest challenge in their science instruction. Therefore, more efforts should be made to help teachers, particularly those who lack teaching experience, learn to use inquiry to teach specific science topics. Third, PD design should take into account teacher background in teaching experience and grade level. PD programs that focus on beginning elementary teachers are much needed. Finally, this study showed that teachers needed considerable PD support when adopting new curriculum standards. This finding has important implications because both the Common Core Curriculum Standards for mathematics and literacy and the Next

Generation Science Standards are currently being implemented in the USA (National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; National Research Council, 2013).

References

Abell, S. K. (2007). Research on science teacher knowledge. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1105–1149). Mahwah, NJ: Lawrence Erlbaum Associates.

American Association for the Advancement of Science. (1993). *Benchmarks for science literacy*. New York, NY: Oxford University Press.

Appleton, K. (2006). Science pedagogical content knowledge and elementary school teachers. In K. Appleton (Ed.), *Elementary science teacher education: International perspectives on contemporary issues and practice* (pp. 31–54). Mahwah, NJ: Erlbaum.

Avraamidou, L., & Zembal-Saul, C. (2010). In search of well-started beginning science teachers: Insights from two first-year elementary teachers. *Journal of Research in Science Teaching, 47*, 661–686.

Banilower, E. R., Heck, D. J., & Weiss, I. R. (2007). Can professional development make the vision of the standards a reality? The impact of the National Science Foundation's Local Systemic Change through Teacher Enhancement Initiative. *Journal of Research in Science Teaching, 44*, 375–395.

Barnett, J., & Hodson, D. (2001). Pedagogical context knowledge: Toward a fuller understanding of what good science teachers know. *Science Education, 85*, 426–453.

Bausmith, J. M., & Barry, C. (2011). Revisiting professional learning communities to increase college readiness: The importance of pedagogical content knowledge. *Educational Researcher, 40*, 175–178. doi:10.3102/0013189x11409927

Bleicher, R. E. (2004). Revisiting the STEBI-B: Measuring self-efficacy in preservice elementary teachers. *School Science and Mathematics, 104*, 383–391.

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*, 3–15.

Borko, H., Jacobs, J., & Koellner, K. (2010). Contemporary approaches to teacher professional development. *International Encyclopedia of Education, 7*, 548–556.

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching, 44*, 613–642.

Davis, E. A., Petish, D., & Smithey, J. (2006). Challenges new science teachers face. *Review of Educational Research, 76*, 607–651.

Friedrichsen, P. J., Abell, S. K., Pareja, E. M., Brown, P. L., Lankford, D. M., & Volkmann, M. J. (2009). Does teaching experience matter? Examining biology teachers' prior knowledge for teaching in an alternative certification program. *Journal of Research in Science Teaching, 46*, 357–383.

Garet, M. S., Porter, A. C., Desimone, L., Birman, B. F., & Yoon, K. S. (2001). What makes professional development effective? Results from a national sample of teachers. *American Educational Research Journal, 38*, 915–945.

Germann, P. J., & Aram, R. J. (1996). Student performances on the science processes of recording data, analyzing data, drawing conclusions, and providing evidence. *Journal of Research in Science Teaching, 33*, 773–798.

Gess-Newsome, J. (1999). Pedagogical content knowledge: An introduction and orientation. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 3–17). Boston, MA: Kluwer.

Glaser, B. G., & Strauss, A. L. (1967). *The discovery of grounded theory: Strategies for qualitative research*. New York, NY: Aldine.

Grossman, P. L. (1990). *The making of a teacher: Teacher knowledge and teacher education*. New York: Teachers College Press.

Gudmundsdottir, S. (1995). The narrative nature of pedagogical content knowledge. In H. McEwan & K. Egan (Eds.), *Narrative in teaching, learning and research* (pp. 24–38). New York, NY: Teachers College Press.

Hashweh, M. (2013). Pedagogical content knowledge: Twenty-five years later. In C. J. Craig, P. C. Meijer & J. Broeckmans (Eds.), *From teacher thinking to teachers and teaching: The evolution of a research community* (Vol. 19, pp. 115–140). Bingley, UK: Emerald Group Publishing Limited.

Hewson, P. W. (2007). Teacher professional development in science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 1179–1203). Mahwah, NJ: Lawrence Erlbaum Associates.

Johnson, C. C. (2006). Effective professional development and change in practice: Barriers science teachers encounter and implications for reform. *School Science and Mathematics, 106*, 150–161.

Jones, M. T., & Eick, C. J. (2007). Implementing inquiry kit curriculum: Obstacles, adaptations, and practical knowledge development in two middle school science teachers. *Science Education, 91*, 492–513.

Kennedy, M. M. (1998). Education reform and subject matter knowledge. *Journal of Research in Science Teaching, 35*, 249–263.

Lee, O., Hart, J. E., Cuevas, P., & Enders, C. (2004). Professional development in inquiry-based science for elementary teachers of diverse student groups. *Journal of Research in Science Teaching, 41*, 1021–1043.

Lee, E., & Luft, J. A. (2008). Experienced secondary science teachers' representation of pedagogical content knowledge. *International Journal of Science Education, 30*, 1343–1363.

Lieberman, A., & Mace, D. H. P. (2008). Teacher learning: The key to educational reform. *Journal of Teacher Education, 59*, 226–234.

Liu, X. F. S., & Meyer, J. P. (2005). Teachers' perceptions of their jobs: A multilevel analysis of the teacher follow-up survey for 1994–95. *Teachers College Record, 107*(5), 985–1003. doi:10.1111/j.1467-9620.2005.00501.x

Loucks-Horsley, S., Love, N., Stiles, K. E., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics* (2nd ed.). Thousand Oaks, CA: Corwin Press.

Loughran, J., Mulhall, P., & Berry, A. (2004). In search of pedagogical content knowledge in science: Ways of articulating and documenting professional practice. *Journal of Research in Science Teaching, 41*, 370–391.

Lumpe, A., Czerniak, C., Haney, J., & Beltyukova, S. (2012). Beliefs about teaching science: The relationship between elementary teachers' participation in professional development and student achievement. *International Journal of Science Education, 34*, 153–166. doi:10.1080/09500693.2010.551222

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 95–132). Boston, MA: Kluwer.

Martens, M. L. (1992). Inhibitors to implementing a problem-solving approach to teaching elementary science: Case study of a teacher in change. *School Science and Mathematics, 92*, 150–156.

Morine-Dershimer, G., & Kent, T. (1999). The complex nature and sources of teachers' pedagogical knowledge. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge: The construct and its implications for science education* (pp. 21–50). Boston, MA: Kluwer.

National Governors Association Center for Best Practices & Council of Chief State School Officers. (2010). *Common core state standards*. Washington, DC: Authors.

National Research Council. (1996). *National Science Education Standards: Observe, interact, change, learn*. Washington, DC: National Academy Press.

National Research Council. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: The National Academies Press.

Oliveira, A. W. (2010). Improving teacher questioning in science inquiry discussions through professional development. *Journal of Research in Science Teaching, 47*, 422–453.

Opfer, V. D., & Pedder, D. (2011). Conceptualizing teacher professional learning. *Review of Educational Research, 81*, 376–407.

Penuel, W. R., Fishman, B. J., Yamaguchi, R., & Gallagher, L. P. (2007). What makes professional development effective? Strategies that foster curriculum implementation. *American Educational Research Journal, 44*, 921–958.

Proctor, M. D., & Marks, Y. (2013). A survey of exemplar teachers' perceptions, use, and access of computer-based games and technology for classroom instruction. *Computers and Education, 62*, 171–180. doi:10.1016/j.compedu.2012.10.022

Ross, J. A., McDougall, D., Hogaboam-Gray, A., & LeSage, A. (2003). A survey measuring elementary teachers' implementation of standards-based mathematics teaching. *Journal for Research in Mathematics Education, 34*, 344–363.

Rotherham, A. J., Mikuta, J., & Freeland, J. (2008). Letter to the next president. *Journal of Teacher Education, 59*, 242–251.

Rourke, L., & Anderson, T. (2004). Validity in quantitative content analysis. *Educational Technology Research and Development, 52*, 5–18.

Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*, 283–312.

Schneider, R. M., & Plasman, K. (2011). Science teacher learning progressions: A review of science teachers' pedagogical content knowledge development. *Review of Educational Research, 81*, 530–565.

Shin, T. S., Koehler, M. J., Lundeberg, M. A., Zhang, M., Eberhardt, J., Zhang, T., & Paik, S. (2010). *The impact of problem-based learning professional development on science teachers' self-efficacy and their teaching practices*. Paper presented at the annual meeting of American Educational Research Association, Denver, CO.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher, 15*(2), 4–14.

Shulman, L. S. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1–22.

Strijbos, J. W., Martens, R. L., Prins, F. J., & Jochems, W. M. G. (2006). Content analysis: What are they talking about? *Computers and Education, 46*, 29–48.

Supovitz, J. A., & Turner, H. M. (2000). The effects of professional development on science teaching practices and classroom culture. *Journal of Research in Science Teaching, 37*, 963–980.

Van Driel, J. H., & Berry, A. (2012). Teacher professional development focusing on pedagogical content knowledge. *Educational Researcher, 41*, 26–28.

Wee, B., Shepardson, D., Fast, J., & Harbor, J. (2007). Teaching and learning about inquiry: Insights and challenges in professional development. *Journal of Science Teacher Education, 18*, 63–89.

Wright, S. P., Horn, S. P., & Sanders, W. L. (1997). Teacher and classroom context effects on student achievement: Implications for teacher evaluation. *Journal of Personnel Evaluation in Education, 11*, 57–67.

Yager, R. E. (2005). Accomplishing the visions for professional development of teachers advocated in the National Science Education Standards. *Journal of Science Teacher Education, 16*, 95–102.

Zhao, Y., & Frank, K. A. (2003). Factors affecting technology uses in schools: An ecological perspective. *American Educational Research Journal, 40*, 807–840.