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Exploring the Design of Scaffolding Pedagogical Instruction for Elementary Preservice Teacher Education

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ABSTRACT

Inquiry, central in science education reforms for decades, is a critical element required in many teacher education programs. However, the instruction of inquiry-oriented pedagogies in those programs has limited impacts on science preservice teachers (PSTs) who arefvn the agent of transforming classroom instruction. The challenges include the limited time PSTs are exposed to the instruction of inquiry in teacher education programs, the gap between educational theories and field practicum of inquiry to which PSTs are exposed, and the less engaging approach to the instruction of educational theories. At the elementary level, there is an additional challenge of PSTs' low motivation toward science and science teaching. In response to these challenges, we designed an innovative approach of scaffolding pedagogical instruction (SPI) and examined its effectiveness in promoting PSTs' competence and disposition toward science and science teaching. In this article, we thoroughly describe the design of SPI and the instrument measuring the learning outcomes. We apply paired *t* tests to compare 85 elementary PSTs' knowledge of inquiry teaching as well as their science identity and science teacher identity before and after receiving SPI. The findings suggest a significantly positive impact of SPI in preparing PSTs with the competence in and disposition toward inquiry teaching.

KEYWORDS
preservice teacher education; elementary science; scaffolding; inquiry teaching

Inquiry-based instruction characterizes a unique expertise that separates science educators from science specialists (National Research Council [NRC], 2012; Osborne, 2014; White & Frederiksen, 1998). A growing number of studies have supported inquiry teaching as a promising approach to current science education reform (Crawford et al., 2014), because it could potentially promote student conceptual understanding of and interest toward science (Minner, Levy, & Century, 2010; Palmer, 2009). The importance of teacher education is widely accepted as a critical venue for science teachers to develop their knowledge and practices (Luft & Hewson, 2014). Many teacher education programs have incorporated a variety of inquiry or inquiry-related strategies and competencies as critical learning objectives, such as the nature of science (NOS; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001), scientific argumentation (Wang & Buck, 2015), and the 5E learning cycle (Bybee et al., 2006). Despite the efforts targeting inquiry teaching, "little has changed regarding how science is taught in the majority of US classrooms" (Capps, Crawford, & Constas, 2012, p. 292).

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This result could stem from the mismatch between the nature of teacher knowledge and the approach to teacher education. There has been argumentation between deregulationists and professionalists about whether teacher knowledge is procedural or propositional, and whether teacher education should be in the format of novice–predecessor apprenticeship or student–teacher academy (Cochran-Smith & Fries, 2001). A mismatch happens when teacher knowledge is procedural, like riding a bike, yet novice teachers learn the theory of "riding a bike" without actually "practicing with riding." The complexity of teacher knowledge (Shulman, 1986) also contributes, as it creates an overwhelming list of competencies expected for novice teachers, each of which normally requires long-term, iterative, and intense efforts (Capps et al., 2012; Desimone, Porter, Garet, Yoon, & Birman, 2002). Thus, science teacher preparation programs have faced the challenge to cover meaningfully a vast amount of content within a limited time. This challenge is greatly related to the instructional approach. If novice teachers rely solely on direct instruction from the educator in learning educational theories, their time in a teacher-preparation program is far from being enough to cover the knowledge and skills for science teaching, or only enough to cover miles wide and inches deep. Inevitably, novice teachers need to be held accountable for their own construction of pedagogical knowledge as much as students do for science learning. In this study, we designed an approach of scaffolding pedagogical instruction (SPI) and explored its effectiveness in promoting elementary preservice teachers' (PSTs') competence of and disposition toward inquiry teaching.

In the following sections, we first introduce the theoretical frameworks guiding our design of the innovative curriculum. We then go over literature regarding different approaches to teacher training to justify the soundness and novelty of our design. In this study, we focus on two types of teacher knowledge: content knowledge and pedagogical knowledge. *Content knowledge* refers to the knowledge of science, such as the knowledge of the water cycle, which serves as the context for pedagogical instruction. *Pedagogical knowledge* refers to the knowledge of teacher practice for effective teaching, such as the knowledge of questioning skills.

Theoretical framework

Inquiry teaching

Inquiry is multifaceted (Osborne, 2014; Schwab, 1962). Scientific inquiry refers to authentic explorative activities of scientists and classroom inquiry refers to the student-centered instructional approach in science classes (NRC, 2012). Classroom inquiry (i.e., inquiry teaching or learning) mimics but does not mirror the work of scientists by incorporating their activities such as defining problems and constructing explanations (Capps et al., 2012). Its importance in science education stems from the alignment of its ontology of learning with that of scientific inquiry (Osborne, 2014). Three fundamental activities of scientific inquiry are raising questions, designing and conducting investigations, and formulating explanations (Bell, Smetana, & Binns, 2005; Colburn, 2000; Schwab, 1962). The three activities are identified as critical practices of classroom inquiry as well (NRC, 2012). Differently, the accountability varies. Students can investigate a question of their own or one raised by their teacher. They can design their own investigation or follow the procedure provided by their teacher. They can summarize their findings or count on their teacher to do that. The situation varies in accordance with factors like student competence and time or equipment availability. The essence of classroom inquiry that separates it from direct instruction is that students actively develop their knowledge by making sense of their experience of exploration (Bell et al., 2005; Colburn, 2000; Osborne, 2014). As Bell et al. (2005) commented, "an activity can still be inquiry-based when the questions and data are provided, as long as students are conducting the analysis and drawing their own conclusions" (p. 30). Classroom inquiry also involves the metacognition of scientific inquiry known as the nature of science (Lederman et al., 2001) or "inquiry into inquiry" (Osborne, 2014, p. 581). The focus of this study is inquiry as a pedagogy, so the term *inquiry* refers to classroom inquiry in the following sections as opposed to scientific inquiry.

Inquiry continuum

The inquiry continuum defines four types of inquiry (Table 1) based on the accountability of students in the three key activities mentioned previously (Alake-Tuenter et al., 2012; Banchi & Bell, 2008; Windschitl, 2003). For confirmation inquiry, a teacher provides the research question, investigatory procedure, and explanation. The purpose of the investigation is to confirm known principles (Leonard, Boakes, & Moore, 2009; Windschitl, 2003). In structured inquiry, students derive the answer to the question raised by a teacher following the investigation procedure provided by the teacher (Alake-Tuenter et al., 2012; Leonard et al., 2009). In guided inquiry, a teacher raises questions for investigation and students take the responsibilities of designing and conducting investigation as well as formulating explanations. Open inquiry is where students are accountable for all of the three key activities. It is most complex for students due to the sophisticated knowledge or skills required and the ambiguity created from student autonomy. Researchers have claimed that open inquiry is achievable to students after they have experienced the other types of inquiry (Bell et al., 2005; Colburn, 2000). From confirmation to open inquiry, class instruction gradually increases student autonomy and relinquishes teacher influence. By controlling teacher involvement in instructional activities, inquiry can shift between the more teacher-centered and more student-centered ends along the continuum.

Scaffolding

As just illustrated, the amount of teacher involvement in terms of guidance or support determines the position of an instruction on the inquiry continuum. To determine the appropriate amount of teacher involvement, Wood, Bruner, and Ross (1976) developed the theory of scaffolding. According to the theory, teachers as the more knowledgeable

Table 1. Inquiry continuum (Banchi & Bell, 2008).

Types of inquiry	Question	Investigation	Explanation
1. Confirmation inquiry: Students confirm a principle through an activity when the results are known in advance	X	X	X
2. Structured inquiry: Students investigate a teacher-presented question through a prescribed procedure	X	X	
3. Guided inquiry: Students investigate a teacher-presented question using student-designed and selected procedures	X		
4. Open inquiry: Students investigate questions that are student formulated through student designed/selected procedures			

Note: X = an activity led by teacher.

others need to control the elements of a learning task that are initially beyond students' competence and focus them on the elements within. This model clearly identifies what teachers should scaffold with the dichotomy of what students can and cannot do, but fails to describe how students shift from "cannot" to "can" or expand their zone of competence with teacher scaffolding. Following the work of Wood and colleagues, Puntambekar and Hubscher (2005) suggested a dynamic model of scaffolding that specifies the interaction between teacher and student. The model contains four elements: intersubjectivity, ongoing diagnosis, calibrated support, and fading.

Intersubjectivity

Intersubjectivity occurs when both teacher and student come to a consensus about the objective of a task or activity (Puntambekar & Hubscher, 2005). It is the mutual agreement, trust, and respect developed from intersubjectivity that allows students to take ownership of the task. Intersubjectivity relies heavily on productive dialogue and allows the participants to learn from each other (van de Pol, Volman, & Beishuizen, 2010). Specifically, students can meaningfully observe and learn from their teacher as the teacher comprehends the students' perception of the task.

Ongoing diagnosis

A teacher assesses students' knowledge and competence through continuous communication with them. The process of ongoing diagnosis enables the teacher to determine the type and amount of support needed by students (Puntambekar & Hubscher, 2005; van de Pol et al., 2010). The knowledge and competence vary across students, and each student progresses with his or her learning at different paces. Thus, ongoing diagnosis sometimes is an asynchronous process.

Calibrated support

The calibration of support is the adjustment that a teacher makes based on the collected information of students. Analogically, once understanding the width of the gap students need to jump across and the length that students can jump, the teacher needs to determine the necessary length of a board used to narrow the gap so that students can finish their own leap. Ongoing analysis and calibrated support epitomize the nature and purpose of scaffolding (Puntambekar & Hubscher, 2005).

Fading

Another distinguishing feature of scaffolding is the gradual elimination of teacher support (Puntambekar & Hubscher, 2005). Scaffolding is not a teacher accomplishing a task on students' behalf, but instead helping students develop their own competence so that they can eventually accomplish the task independently. Using the same analogy as earlier, the teacher needs to withdraw the board gradually to grant students the opportunities to practice jumping until they can jump across the gap without the board.

Scaffolding shares many features with inquiry. They both value student accountability for their learning and emphasize the critical role of fluctuating teacher support based on students' needs. The component of fading echoes the shift from the teacher-centered end to the student-centered one along the inquiry continuum. Teaching in a sequence from confirmation inquiry to open inquiry is an example of scaffolding. Inquiry and scaffolding have been widely used in science education for students, but not much in pedagogical instruction for PSTs.

Effective teacher education programs

In this study, we applied the theories of inquiry and scaffolding to design the innovative curriculum. We also referred to the features of effective teacher education programs with which the curriculum should be aligned. Desimone et al. (2002) identified six key features:

(1) *Reform type* refers to two main approaches to teacher education that are traditional, such as workshops and college courses, and reformed, such as study groups, teacher networks, and research projects.
(2) *Duration* is the hours of participation and the length of reoccurring or follow-up activities.
(3) *Collective participation* is the collaboration between teachers from the same school, grade, or department to develop shared experiences on target knowledge or skills.
(4) *Active learning* is the active engagement of teachers in the analysis of teaching and learning.
(5) *Coherence* is the objectives of teacher education being "consistent with teachers' goals and aligned with state standards and assessment" (p. 83).
(6) *Content focus* is the focus on "improving and deepening teachers' content knowledge" (p. 83).The six features are identical to the effective features identified by Garet, Porter, Desimone, Birman, and Yoon (2001).

Through a thorough review of peer-reviewed literature on science teacher education programs, Wilson (2013) nominated 10 key features, among which focusing on specific content, engaging teachers in active learning, enabling the collective participation of teacher, coherence, and sufficient duration align with the work of Desimone et al. (2002). There are five additional features, which are activities being close to practice, taking into account participants' physical and psychological comfort, teachers being immersed in inquiry experiences and witnessing models of inquiry teaching, using curriculum materials educative for teachers and students, and teachers receiving direct instruction on innovative teaching.

In designing the curriculum of SPI, we followed the 10 features just listed, except for the feature of direct instruction. As stated earlier, the conflict between the limited time in PST preparation programs and the complex nature of teacher knowledge hinders the direct instruction of all the knowledge and skills necessary for effective science teaching. On the other hand, it is uncertain whether teacher knowledge is procedural or propositional, and correspondingly whether teacher education should be through practice-based apprenticeship or laboratory-based scholarship (Darling-Hammond & Bransford, 2005; Zeichner, 2010). If teacher knowledge is propositional as scientific content knowledge, the inquiry approach should apply to teacher education as well; that is, active construction of teacher knowledge is better rather than passively imparted to PSTs. The SPI curriculum that we designed is an alternative to direct instruction. We desired to explore its feasibility and effectiveness. In the following section, we review the approaches to teacher education from existing literature.

Literature review

In this section, we review some approaches to inquiry pedagogies for teacher education used in both teacher preparation programs for PSTs and professional development programs for in-service teachers (ISTs). Through the reviews, we summarize the patterns of existing teacher education and justify the feasibility and novelty of the SPI approach.

Teacher preparation programs

Sadler (2006) designed a teacher preparation program targeting argumentation. The program started with a discussion of excerpts from an article related to argumentation in school settings. Then the instructor taught PSTs the model of argumentation. Afterward, the PSTs practiced with argumentation by identifying argument patterns from secondary science textbooks and analyzing their own arguments. In their study, Mavhunga and Rollnick (2013) developed an intervention to promote PSTs' understanding of pedagogical content knowledge (PCK). The intervention started with the PSTs reading articles about PCK. Then the authors explained the theory of PCK. Afterward, the authors demonstrated the implementation of the PCK model in the context of chemical equilibrium, and reflected on how each component of the PCK model applied. Barnhart and van Es (2015) applied an intervention that started with exposing PSTs to the theories about analytic and responsive teaching practice, followed by the instructor-designed practice of analyzing student thinking from instructional videos. Finally, the PSTs practiced with the target skills through designing, video recording, and reflecting on their own teaching. Despite the various objectives, the three programs just mentioned share one similarity: They start with direct instruction on the target pedagogical knowledge or skill—argumentation, PCK, and analytic practice, respectively—by referring to authoritative resources in terms of readings or instructors. Then the following activities serve as the practice of the target knowledge or skill, which functions similar to confirmatory labs in traditional science "lecturing." The learners (i.e., PSTs) rely heavily on authority to obtain knowledge. Thus, those programs adopted an approach of direct instruction to teacher education where delivery of the learning objectives is directly to the learners from teacher educators.

Lederman et al. (2001) designed a series of activities to teach aspects of NOS. First, the authors designed a new course that taught NOS to the PSTs. Then the PSTs participated in a science research internship and observed the investigation of a practicing scientist in a science lab. Finally, the PSTs designed and presented two lessons addressing NOS. In this study, the authors applied an activity of immersing the PSTs in an authentic scientific exploration, which came after the instruction of NOS. The activity served as the practice or verification of the instruction. Additionally, the authors strongly encouraged the PSTs to include NOS in their lesson designs and provided them with a packet of NOS activities. Overall, the instruction of NOS from this program is aligned with direct instruction.

As reviewed in the literature earlier, PST training programs mainly use direct instruction on pedagogical knowledge or skills. If pedagogical knowledge has a propositional nature, it is reasonable to assume that direct instruction on pedagogical knowledge might result in problems similar to those on scientific content knowledge such as impersonality, low motivation, and disconnection between theory and practice (Cobern et al., 2010; Dean & Kuhn, 2007). Moreover, educational theories are less likely to guide teacher practice than teachers' opinions about proper and possible actions (Wang & Buck, 2016; Windschitl, 2003). Thus, direct instruction might be incapable of imparting pedagogical knowledge unless PSTs intrinsically accept the knowledge.

Another challenge associated with direction instruction in the context of PST preparation is that the limited time of a program could hinder its influences on PSTs' acceptance and mastery of a pedagogy like inquiry (Lederman & Lederman, 2015; Lotter, Harwood, & Bonner, 2007; Penuel, Gallagher, & Moorthy, 2011). Teacher education is a slow and tinkering process (Huberman, 1995), and so is PST preparation. Convincing PSTs to accept a reformed pedagogy, such as inquiry, that is different from their own earlier science classroom experiences, requires considerable time for them to develop both the competence in and disposition toward it (Davis & Krajcik, 2005). The problem of limited time is even more severe in elementary PST preparation, because elementary PSTs sometimes are facing the overwhelming list of knowledge and skills required by different subjects and they have the option of not teaching science in their future career (Brand & Moore, 2011). The situation might lead to the problem of "miles wide and inches deep" in PSTs' knowledge for science teaching.

Professional development programs

Professional development programs also rely on direct instruction for ISTs. Lee, Maerten-Rivera, Penfield, LeRoy, and Secada (2008) designed workshops focusing on multiple objectives, such as science content, hands-on activities, and common student misconceptions. The instruction of an objective followed a sequence from project personnel discussing or modeling the knowledge or skill for teachers to the teachers practicing with it later. Take scientific inquiry, for instance: Project personnel introduced the theories of scientific inquiry and discussed its implementation in teaching. Then they demonstrated the structure of inquiry teaching. Afterward, the participating teachers worked on the designs of scientific inquiry activities, presented their work to the entire group, and discussed the practical approaches.

Some professional development programs adopt more reformed approaches to teacher education. Lotter et al. (2007) described an inquiry-oriented program consisting of two sessions: the morning inquiry workshops and the afternoon laboratory research. In the morning workshops, the ISTs experienced inquiry teaching aimed at solving a student-learning bottleneck. Then they developed and presented an inquiry-oriented lesson with the focus on bottlenecks. In the afternoon lab, the ISTs worked with college science faculty to experience authentic scientific inquiry and reflected on how they could translate scientific inquiry into classrooms. Similarly, Akerson, Hanson, and Cullen (2007) designed a workshop consisting of two components: (a) morning sessions where the ISTs experienced learning physics through guided inquiry, and (b) afternoon sessions where they received instruction about pedagogy for teaching physics, inquiry, and NOS to students. Blanchard, Southerland, and Granger (2009) introduced a program called Marine Ecology for Teachers (MET). MET focused on transforming scientific inquiry to inquiry teaching. The ISTs participated in authentic research experiences with a scientist, and later reflected on various aspects of the research process and the pedagogical features of the inquiry modeled by the scientist under the guidance of master teachers. The scientist also modeled inquiry teaching because he perceived the ISTs as individuals who knew nothing about the scientific content. In the three studies, the teacher-learners were not imparted the target theories of pedagogy from the beginning but exposed to the scenarios to which the theories applied. The instruction of the theories happened after the learners had developed some understandings from the exposure.

Brand and Moore (2011) designed a constructivist sociocultural model that consisted of two parts: inquiry-based workshops and unit design, implementation, and reflection in classrooms. During the first part, the ISTs explored the schoolyard habitat to understand the environmental conditions around their school. They experienced authentic scientific inquiry activities from the perspective of students, such as mapping the school environment and analyzing soil samples. Afterward, they reflected on the process of exploration and discussed the curricular adaptions. Following the workshops, the ISTs in their classroom designed, implemented, reviewed, and revised a unit of science lessons that simulated their own explorative experience. Compared to the aforementioned three studies, the instruction of pedagogy (i.e., inquiry teaching) in this one is more learner-centered or inquiry-oriented because it was the ISTs rather than teacher educators who transited the experience with scientific inquiry to the practice of inquiry teaching. This result echoes the argument from Capps et al. (2012) that immersing teachers in authentic scientific inquiry can help them enact inquiry teaching in their classroom. The authors claimed that the constructivist model positively affected the ISTs' engagement in their own professional development.

The success of reformative approaches to pedagogical instruction used in IST education programs has provided empirical evidence that supports the feasibility and efficacy of the inquiry approach in terms of exposing teachers to authentic scientific inquiry or modeled inquiry science classes prior to the discussion of pedagogy. It also shows that the inquiry approach varies in formats according to the different amounts of support and guidance from teacher educators during the knowledge development of learners, which suggests that the inquiry continuum with the educator-centered and learner-centered ends might apply to PST education. If novice teachers can construct their pedagogical knowledge through an inquiry-based approach (i.e., SPI), teachers' pedagogical knowledge could have a propositional nature and practice-based apprenticeship might be insufficient for teacher training.

Summary

In this study, we take the trial of designing an inquiry-based approach to pedagogical instruction (i.e., the SPI curriculum) in the context of science PST training. With this curriculum, we do not deny "direct instruction" for teacher education. The preference for direct instruction might stem from the emphasis of explicit instruction, as Penuel et al. (2011) found that the programs with explicit instruction on pedagogical knowledge out-performed counterparts without this instruction in promoting learners' science teaching practices. We want to address that direct instruction is not equivalent to explicit instruction, but the direct delivery of knowledge from authoritative resources without sufficiently engaging learners in a phenomenon in question. In SPI, we combine PSTs' exposure to teaching practices and explicit instruction of pedagogical theories. Innovatively, we adopt the shift along the inquiry continuum as a specific means of scaffolding for pedagogical instruction. Our main concern is the effectiveness of the curriculum in prompting PSTs' competence and disposition with which they can continuously construct their knowledge of inquiry even beyond the program. Our research questions are as follows:

Q1. Was the SPI curriculum effective in promoting elementary PSTs' knowledge of science content and inquiry pedagogies?

Q2. Was the SPI curriculum effective in promoting elementary PSTs' disposition toward science teaching in terms of their science and science teacher identities?

Method

The foci of this study are to introduce the design of an inquiry-oriented curriculum for PST preparation and preliminarily investigate its effectiveness. Quantitative method, specifically paired *t* tests (Cohen, Manion, & Morrison, 2007), was used to make pre–post comparison on PSTs' competence and disposition.

Participants and context

The participants were 85 elementary PSTs from three sections of a science methods course in Spring 2017 provided by a large Southern U.S. university. The PSTs were in the second block of a four-block (2 years in total) program. In this program, first-block PSTs took general courses about classroom management, teaching at elementary school, and professionalism as teachers. In the second block, PSTs took instructional methods courses in different subject areas, including literacy, math, science, and social studies. Meanwhile, they started their field practicum 1 full day or 2 half-days a week. In Blocks 3 and 4, they worked in the field 4 full days a week. In addition, they needed to take courses about advanced math methods, advanced literacy methods, special education, and English as a second language education. Eventually, they would need to take a statewide teacher certification test to be licensed as teachers. This was the only course in this program where the PSTs learned about science teaching. They met in the methods course once per week for 3 hr. Among the 85 PSTs, there were 3 men (3.5%) and 82 women (96.5%). The ethnicity composition was 66 Whites (77.6%), 16 Hispanics (18.8%), 2 Asians (2.4%), and 1 Black (1.2%). The three sections were taught by four instructors, including the designer of the curriculum, who are experienced science teachers and were supporters of inquiry-oriented science teaching. The instructors had been training science PSTs about inquiry for years. Team teaching was applied and each instructor taught one of the four modules across all three sections. The teaching team met weekly to debrief the prior week and adjust for the coming week. Thus, we were continuously diagnosing PSTs' learning and calibrating instructor support accordingly.

SPI

Four instructional modules (Table 2) were designed in line with the inquiry continuum (Table 1). Each module spanned 3 weeks and concentrated on one topic for pedagogical knowledge and one for content knowledge. In the first 2 weeks of each module, the instructors taught the target knowledge through a certain approach on the inquiry continuum (Table 1). In the third week, the PSTs individually practiced the target

Table 2. The four modules of the scaffolding curriculum.

Inquiry type	Confirmation inquiry	Structured inquiry	Guided inquiry	Open inquiry
Module focus	Module 1, Week 1 5E + motion Module 1, Week 2 Importance of 5E + force	Module 2, Week 1 Productive questions + the water cycle Module 2, Week 2 Bloom's taxonomy questions + weather/ climate	Module 3, Week 1 Argumentation + organisms &ecosystem Module 3, Week 2 Instructional strategies for argumentation + food chain	Module 4, Week 1 Crosscutting concepts + energy types Module 4, Week 2 Designing units of lessons + energy transformation
	Modules 1–3, Week 3 PSTs practice the target pedagogical skill with peers and present their video of that practice in class individually			Module 4, Week 3 Instruction of NOS
Instructor	Mr. V	Ms. M	Ms. R + Mr. V	Ms. O
Pedagogical question(s)	Instructor-asked	Instructor-asked	Instructor-asked	PST-asked
Exploration modeled lesson	• "Rehearsal" • Instructor-led in-the-moment reflection	• Nonstop modeling • Post instructor-led reflection	• Nonstop modeling • Post PST-led reflection	• Nonstop modeling • Post PST-led reflection
Explicit instruction	• Instructor-led • Readings before instruction	• Instructor led • Readings after instruction	• PST-led • Readings after instruction	• PST-led • Readings not provided

Note: NOS = nature of science; PST = preservice teacher.

knowledge in class with their peers. For example, the 5E learning cycle and physical science were the objectives of Module 1. Thus, the PSTs needed to practice with peers the skill of engaging students into a topic of physical science in the third week of Module 1.

Module 1

Mr. V, who had 5 years of experience teaching science and 5 years of experience training science teachers, taught Module 1 though confirmation inquiry. At the beginning of this module, the PSTs were assigned readings about the 5E learning cycle (Bybee et al., 2006) before coming to class. In each of the first 2 weeks, Mr. V held class discussion about the readings at the beginning and thoroughly explained the 5E model to the PSTs. Then he modeled a lesson through the 5E model regarding physical science, during which he paused after each E to explicitly reflect on what he had done for that E and why. The 2 weeks had slightly different focuses on pedagogical knowledge. The first week was about what the 5E model is and why 5E aligns with inquiry and the second one was about why 5E and inquiry are important and how they are different from direct instruction. In Module 1, explicit instruction of the pedagogical knowledge (i.e., 5E and inquiry) happened before exposing the PSTs to the modeled lesson using 5E and it was given by the instructor in reference to the readings.

Module 2

Ms. M, who had 18 years of experience teaching science and 5 years of experience training science teachers, taught Module 2 through structured inquiry. No readings were given at the beginning of this module about the pedagogical topic of questioning. Ms. M raised the overarching question of "What types of questions can prompt active responses from students?" for Week 1 and "What thinking skills do students need to answer a certain question?" for Week 2. After some quick discussion about the overarching question, Ms. M modeled an inquiry lesson about earth science, during which she paused at certain questions that appear on a worksheet for the PSTs to analyze what they felt when asked those questions (Week 1) or what they needed to do to answer those questions (Week 2). Ms. M gave no instruction on questioning during the modeled lesson, but led the PSTs to reflect on questions that prompted active responses (Week 1) or the thinking skills needed to answer different questions (Week 2) afterward. Finally, Ms. M summarized the key pedagogical knowledge of productive questions (Week 1) and Bloom's taxonomy questions (Week 2) and provided the related readings for the PSTs to compare the knowledge generated from class with that stated in the readings. In Module 2, the explicit instruction of the pedagogical knowledge (i.e., questioning), happened after the modeled lesson and it was led by the instructor. The readings also served as part of the explicit instruction.

Module 3

Ms. R, who had 11 years of experience teaching science and 2 years of experience mentoring science teachers, cotaught Module 3 with Mr. V through guided inquiry. They raised the overarching question of "What is scientific argumentation?" for Week 1 and "What instructional strategies can science teachers use to scaffold classroom argumentation?" for Week 2. After a quick discussion among the PSTs themselves, the instructors modeled an inquiry lesson about life science with argumentation embedded. For instance, they enacted a class-debate activity about the optimum solution to zebra mussels as a local invasive species in Week 2. No pedagogical instruction was given during the modeled lesson. Afterward, the PSTs summarized the significance and structure of scientific argumentation (Week 1) and argumentation-related instructional strategies (Week 2) under the guidance of the instructors, and compared their self-generated knowledge with that stated in the readings provided at the end. In Module 3, the explicit instruction of the pedagogical knowledge (i.e., argumentation) happened after the modeled lesson and it was led by the PSTs. The readings also served as part of the explicit instruction.

Module 4

Ms. O, who had 23 years of experience teaching science and 8 years of experience training science teachers, taught Module 4 through open inquiry. Ms. O in Week 1 presented to the PSTs a paragraph introducing the problem of fragmented science. After the PSTs briefly discussed fragmented science from their experience with science learning or teaching, each group raised three questions regarding fragmented science or crosscutting concepts. Then Ms. O modeled a lesson about different types of energy involved in the scenarios covered in the previous three modules; for example, solar energy and thermal energy involved in the water cycle (Module 2) and mechanical energy involved in motion (Module 1). Finally, the PSTs answered their own questions raised at the beginning and were given time to brainstorm crosscutting concepts other than energy. In Week 2, the PSTs were given state science standards organized according to crosscutting concepts. For instance, we put together the standards about the water cycle, the Moon phases, the cycle of melting and solidification, and the life cycle, as cycle is the interweaving theme. The PSTs worked collaboratively to first identify the crosscutting concept of the standards assigned to them, design a unit of science lessons aligned with the standards, and share their units with each other. Ms. O served as the facilitator during both classes. In Module 4, the explicit instruction of the pedagogical knowledge (i.e., crosscutting concepts) happened after the modeled lesson and it was led by the PSTs. No readings were provided.

Noticeably, the designs of the four modules (Table 2) match the four types of inquiry (Table 1). From Module 1 to Module 4, it is a shift from the educator-centered end to the learner-centered one along the inquiry continuum. The sequence is also aligned with the model of scaffolding (Puntambekar & Hubscher, 2005) because the teaching team gradually withdrew their scaffold during the PSTs' pedagogical learning. Regardless of the various foci of each module, the instruction relied less and less on the instructors and more and more on the PSTs. The new curriculum of SPI also meets most of the key features of effective teacher education programs (Desimone et al., 2002; Wilson, 2013) except for duration and direct instruction. Three weeks for a pedagogical topic might not be sufficient, and direct instruction was only used in Module 1. We wanted to investigate the impact of the fading support from the instructors, especially Module 4, where the support is minimal.

Data collection and analysis

The curriculum of SPI was designed to develop PSTs' competence in and disposition toward inquiry. For competence, we measured the PSTs' knowledge of science and inquiry pedagogies as the two pillars supporting science teaching (Shulman, 1986). For disposition, we adopted the concept of context-oriented identity (Hazari, Sonnert, Sadler, & Shanahan, 2010) because it describes how people see themselves connected to a field and predicts their involvement and sustention in that field. We measured the PSTs' science and science teacher identities as how they see themselves in relation to science and science teaching.

Knowledge of science and inquiry pedagogies

The measurement of PSTs' knowledge is threefold: knowledge of content and pedagogies measured by module quizzes, knowledge of the inquiry approach measured by the Pedagogy of Science Teaching Tests (POSTT) survey (Cobern et al., 2014), and knowledge of NOS measured by the survey of View of Nature of Science - C (VNOS-C) (Lederman et al., 2001).

Each of the four modules contained pre and post quizzes measuring the PSTs' knowledge of the scientific and pedagogical topics assigned to that module. Both quizzes covered the identical concepts and shared the same format of both multiple-choice and short-answer questions, but used different contexts for questions. The multiple-choice questions had only one correct answer (Appendix Part A), and the short-answer questions had the rubric for grading. For the short-answer questions about questioning from Module 2 Pre, for example (Appendix Part A), a PST would receive 1 point if his or her answer to Question 1 was "No, the statement is incorrect," and another point if the justification was scientifically correct. For Question 2, a correct answer would be a productive question that could guide the student to notice his or her misconception (Elstgeest, 1985), such as "Would the water disappear if there is no wind?" An incorrect answer would be an unproductive question, such as "Why do you think so?" or "Can you elaborate on that a little more?" For Question 3, a PST would earn 1 point if he or she could correctly identify the level of a question in Bloom's taxonomy (Lord & Baviskar, 2007) and another point if he or she could justify the answer. Two well-trained graders scored short-answer questions and had a discussion afterward to reach interrater agreement. Each question had a dichotomous score of either 1 point (correct) or 0 point (incorrect), and each quiz had a total of 20 points.

After collecting the pre- and postmodule quizzes, we first used item response theory (IRT) (Embretson & Reise, 2000), especially the Rasch model (Wolfe & Smith, 2007), to analyze the reliability of the quizzes in assessing the PSTs' scientific and pedagogical knowledge. We ran the Rasch model (one parameter) first and calculated the mean square (MNSQ) of each question. Then we assumed different levels of guessing for multiple-choice questions and no guessing for short-answer questions. In response, we ran the three-parameter IRT model (three parameters), and calculated MNSQ again. Afterward, we kept the questions with an acceptable fit and an MNSQ value that fell into the range from 0.6 to 1.4 (Linacre, 2013). The PSTs' percentage score was calculated for each quiz based on the remaining question; that is, the received score divided by the total score of the questions left.

POSTT surveys contain questions of teaching various scientific topics through four different approaches. Respondents need to identify each approach as didactic direct, active direct, guided inquiry, or open inquiry (Cobern et al., 2014). We selected the questions for which topic matches the content involved in the curriculum and required the PSTs to identify each approach as either inquiry (guided inquiry and open inquiry) or noninquiry (didactic direct and active direct; Appendix Part B). A PST would earn 1 point for one correct identification of A, B, C, or D. We selected five questions from the POSTT repertoire for pre and another five for post. Each POSTT survey was worth 20 points in total.

NOS understanding is closely related to the knowledge of inquiry teaching (Crawford, 2007). We used the VNOS-C survey (Lederman et al., 2001) that contains 10 open-ended questions measuring different aspects of NOS. The authors suggested follow-up interviews with survey respondents to confirm the analysis of their understanding of NOS. However, it is unwieldy to conduct interviews with 85 individuals. Instead, we compared the PSTs' answer with the exemplary naive or informed answer to each question provided by the authors (Appendix Part C), and documented a score among a more naive answer (0), a more informed answer (1), and an undeterminable answer (?). Two well-trained graders scored the PSTs' responses and held a discussion afterward to reach interrater agreement. We used the questions that had a rate of undeterminable answers less than 25% (about 20 PSTs) for both pre and post VNOS-C. There were six questions left (i.e., Q3, Q5, Q6, Q8, Q9, and Q10; Lederman et al., 2001, p. 509) that assessed the PSTs' understanding of empirical NOS, the difference between theories and laws, tentative NOS, subjective and objective NOS, creative and imaginative NOS, observation and inference, and the social and cultural embeddedness of science. Both pre and post VNOS-C surveys had a total of 6 points.

Science identity and science teacher identity

Context-oriented identity is how people see themselves in relation to a field as a result of their experiences with it (Hazari et al., 2010). Science identity (SID) and science teacher identity (STID), which are context-oriented, are about whether people see themselves as a science person and a science teacher, respectively. Context-oriented identity can predict people's sense of belonging and persistence

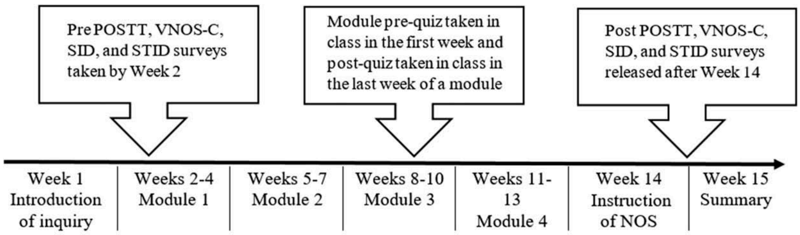

Figure 1. Timeline of data collection.

in a field (Carlone & Harryson, 2007). Thus, SID and STID together can describe the PSTs' disposition toward science teaching. We adopted the model of context-oriented identity and adapted the correlated identity survey (Hazari et al., 2010) to measure the PSTs' SID and STID (Appendix Part D). Each item of the identity survey was scored on a Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). To validate the two surveys of SID and STID, we ran confirmatory factor analysis (CFA) and calculated Cronbach's alpha (Bland & Altman, 1997) on both pre- and post-surveys. Afterward, we added the average scores of the three components of identity (Hazari et al., 2010)—Recognition (rcg), Competence (cmp), and Interest (int)—as a PST's identity score; that is, SID/STID = Ave (rcg items) + Ave (cmp items) + Ave (int items).

Figure 1 shows the timeline of data collection. Module pre and post quizzes were administered at the beginning of the first week and the end of the third week of each module. The PSTs needed to take the quizzes in class individually without any support. The surveys were administered as assignments to guarantee the response rate. Pre surveys of POSTT, VNOS-C, SID, and STID were due by the end of the second week so the PSTs would have enough time to accomplish them. The post versions of the surveys were released after Week 14 to guarantee that the PSTs received all the necessary instruction before taking them. All the surveys were administered as assignments but graded on accomplishment. This way, we could guarantee that the PSTs took those surveys and their responses were a true representation of individual PSTs.

Summary

To answer the research questions, we used paired t tests to make pre–post comparisons on the aforementioned variables. We calculated Cohen's d (Cohen, 1988) to measure the significance of the pre–post difference in reference to individuals' variance (small = 0.2, medium = 0.5, large = 0.8), and normalized gain (Hake, 1998) to measure the significance of the pre and post difference in reference to the maximum gain that could possibly be achieved (small < 0.3, medium = 0.3–0.6, large > 0.7). With the findings, we summarized the effectiveness of the curriculum of SPI in promoting the PSTs' competence and disposition for science teaching.

Findings and discussion

Q1. Knowledge of science and inquiry teaching

Module quizzes

We used the items from module quizzes with MNSQ values acceptable for both Rasch and the three-parameter IRT models. Then we calculated each PST's percentage score for all eight quizzes. For example, the Module 1 pre quiz has 19 items that have acceptable fit, thus the Module 1 pre quiz has a total of 19 points. A PST who earned 16 points out of 19 would receive a percentage score of 16/19 = 84.2%, meaning that the PST got the correct rate of 84.2% among the 19 valid questions from the Module 1 pre quiz.

The paired *t*-test results (Table 3) show that the PSTs have significantly developed their scientific and pedagogical knowledge addressed in all four modules. The <g> value is medium for Modules 1 and 4, and small for Modules 2 and 3. The *d* value is large for Modules 1, 2, and 4, and medium for Module 3. This result suggests that Modules 1 and 4 have helped a large portion of the PSTs achieve a considerable gain, Module 2 has helped a large portion of the PSTs achieve a noticeable gain, and Module 3 has helped a considerable portion of the PSTs achieve a noticeable gain in the associated content. In comparing across the four modules, the patterns of the <g> and *d* values are similar because they both decrease at first and then bounce back in the last module. The difference in effect sizes could stem from the distinctive difficulty levels of the content covered or the various characteristics of the instruction given by different instructors in the four modules. On the other hand, there could be a possibility that the pattern aligns with the inquiry-oriented approach where the PSTs struggled first and then had an "a-ha" moment after Module 3. The effect sizes were the largest (<g>) or the second largest (*d*) in Module 1, which is probably because confirmation inquiry was the approach with which the PSTs were most familiar as they received the most support from the instructor. The effect sizes went down as the instructors withdrew their support in Module 2 and Module 3 where the PSTs probably experienced frustration or struggled, as they would do with inquiry in science. In Module 4, the effect sizes went up to the second largest (<g>) or the largest (*d*) probably because the PSTs had been used to the inquiry approach to knowledge

Table 3. Paired *t* tests of pre and post assessments.

	Pre *M*/Pre Max	*SD*	Post *M*/Post Max	*SD*	|*t*|(*df*)	*p* value	<g>	*d*
Module 1 quizzes	71.1%/100%	14.1%	87.5%/100%	12.0%	9.61(80)	***	0.57	1.25
Module 2 Quizzes	59.6%/100%	13.9%	70.0%/100%	11.6%	5.09(82)	***	0.26	0.81
Module 3 quizzes	69.8%/100%	16.1%	76.4%/100%	13.9%	3.74(80)	***	0.22	0.44
Module 4 quizzes	55.8%/100%	12.6%	77.2%/100%	13.7%	13.3(77)	***	0.48	1.63
POSTT	17.40/20	2.71	18/20	2.56	2.75(69)	0.0076 **	0.23	0.23
VNOS-C	1.10/6	1.00	1.83/6	1.28	4.47(77)	***	0.15	0.64
SID	9.28/15	2.51	10.44/15	2.41	5.84(75)	***	0.20	0.47
STID	9.38/15	2.39	11.07/15	2.20	7.33(75)	***	0.30	0.74

Note: POSTT = Pedagogy of Science Teaching Tests; VNOS-C = View of Nature of Science - C; SID = science identity; STID = science teacher identity.
*p < .05. **p < .01. ***p < .001.

construction. Thus, although open inquiry used in Module 4 used the least support from the instructor, the PSTs still had a considerable increase in their knowledge.

POSTT and VNOS-C. The paired t tests (Table 3) suggest that the curriculum of SPI has significantly promoted the PSTs' knowledge of inquiry teaching and NOS. The PSTs developed from 17.40/20 to 18.00/20 for POSTT (87.00% and 90.00%, respectively). This result suggests either a ceiling effect of POSTT or the PSTs' mastery of the knowledge of differentiating inquiry teaching from direct instruction. The PSTs' NOS score developed from 18.33% (1.10/6) to 30.55% (1.83/6). This result suggests either a floor effect of VNOS-C or the limited impact of SPI in promoting the PSTs' knowledge of NOS.

Due to the uncertainty, we used the Rasch model and three-parameter IRT model to assess the validity of POSTT and VNOS-C, respectively. The MNSQ values show that all the items have acceptable fit. Thus, it is reasonable to infer that the POSTT and VNOS-C scores could represent the PSTs' knowledge of inquiry and NOS. The <g> values for both POSTT and VNOS-C are small (i.e., 0.23 and 0.15). The d value for POSTT (0.23) is small but medium for VNOS-C (0.64). Altogether, the data suggest that the PSTs understood the difference between inquiry teaching and direct instruction in various science content areas prior to the four modules. They might have accessed inquiry teaching before coming to this course or the instruction on inquiry in the first week (Figure 1) successfully illustrated the characteristics of inquiry teaching. The following instruction from the four modules significantly promoted the understanding of inquiry of only a small portion of the PSTs to a noticeable extent. The SPI curriculum has significantly promoted the NOS understanding of a considerable portion of the PSTs only to a noticeable extent. This result echoes the claim that NOS is a challenging concept and the development of informed NOS views is nonlinear (Lederman et al., 2001).

Q2. Science identity and science teacher identity

Figure 2 shows the CFA of the SID and STID models (Appendix Part D) measured by both pre and post surveys. The majority of the factor loadings (> .7) and factor correlations (< .8) are acceptable. Table 4 summarizes the Cronbach's alpha and the commonly used model fit indexes (Schreiber, Nora, Stage, Barlow, & King, 2006), including chi-square (χ^2), root mean square error of approximation (RMSEA), comparative fit index (CFI), and standardized root mean residual (SRMR). Cronbach's alpha suggests that the inner consistency of the two models are excellent (> .70). The model fit indicated by CFI is good (> .90). The SRMR values are acceptable (< .10) except for post-STID. RMSEA(< .10) values are a little problematic because they are all above 0.10. However, their lower limit of the 90% confidence interval is within the acceptable range. Moreover, the patterns of the measurement from pre and post surveys match each other in all regards. Generally, the models of SID and STID have acceptable validity and reliability. The t-test comparison (Table 3) suggests that both SID and STID have increased significantly for the PSTs. The <g> values are small and the d value is medium for SID and large for STID. The data suggest that the SPI curriculum has made a considerable portion of the PSTs feel more a science person and a large portion of the PSTs feel more a science teacher, both to a noticeable extent. This result is reasonable because context-oriented identity is less likely to change greatly within a short amount of time (Hazari et al., 2010).

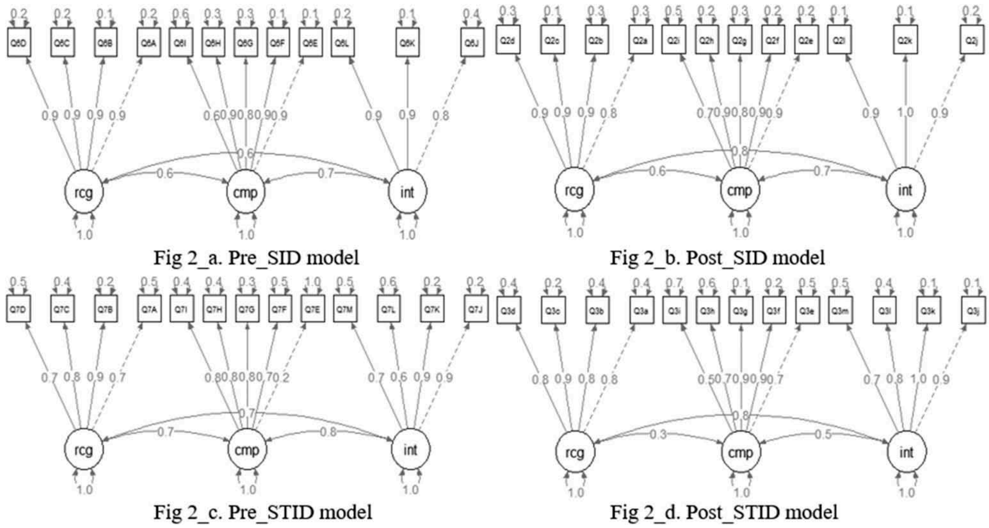

Figure 2. Path disgrams of the science identity (SID) and science teacher identity (STID) models.

Table 4. Cronbach's alpha and model fit indexes of the SID and STID models.

	Cronbach's α	$\chi^2(df)$	RMSEA	RMSEA, 90% lower	RMSEA, 90% upper	CFI	SRMR
Pre-SID	.94	105.22(51)	0.116	0.084	0.147	0.94	0.056
Post-SID	.95	98.16(51)	0.108	0.075	0.139	0.95	0.070
Pre-STID	.90	118.81(62)	0.108	0.078	0.137	0.90	0.081
Post- STID	.91	132.25(62)	0.119	0.091	0.147	0.91	0.112

Note: n = 85. SID = science identity; STID = science teacher identity; RMSEA = root mean square error of approximation; CFI = comparative fit index; SRMR = standardized root mean residual.
$^{*}p$ < .05. $^{**}p$ < .01. $^{***}p$ < .001.

Conclusions

This study is a pilot exploration of an innovative approach to science PST preparation in line with the frameworks of inquiry spectrum, scaffolding, and key features of effective teacher education programs. It has yielded positive findings with which we feel confident to answer the research questions that the SPI curriculum was effective in promoting elementary PSTs' knowledge of science content and inquiry pedagogies (Q1) and their disposition toward science teaching in terms of their science and science teacher identities (Q2). Thus, the inquiry-oriented approach to teacher education can apply to PST preparation. The pre–post difference is statistically significant for all variables measured. The Cohen's *d* values are mostly medium or large, with only one small value for POSTTT, which suggests that the effectiveness of the SPI curriculum has a wide-ranging impact. In other words, a considerable portion of the PSTs have benefited from the SPI curriculum regardless of their various backgrounds. This result reflects the learner-centered nature of the curriculum. It is specifically encouraging of the progress that the PSTs have made in Module 4 with the least amount of instructor support, which suggests that the SPI approach, as an alternative to direct instruction (Wilson, 2013), could also help with PSTs' learning. Generally, the

SPI curriculum has prepared the PSTs with some competence and disposition with which they would be more capable and willing to continuously develop their profession for science teaching.

The science methods course where the study was conducted was the only one where the PSTs received the instruction on the theories of science teaching. In this course, we have narrowed our focus to four scientific topics and four pedagogical topics within a semester. The content covered is far from being enough for the PSTs to be qualified science teachers (Shulman, 1986). The PSTs inevitably need to rely on themselves for further knowledge construction. Besides, the PSTs were placed in the field and taking instructional methods courses in other subjects while taking this course. Other than the SPI curriculum, their knowledge or practice of science teaching might also be shaped by theories of teaching other subjects, their field practicum, or their observations of the teaching given by their mentor teacher. Those different sources of information might not reconcile with or even contradict each other (Brown & Melear, 2006; Feiman-Nemser, 2001). For instance, a PST might learn the theory of inquiry teaching from the science methods course but observe his or her mentor teacher lecturing in the field all the time. Thus, the PSTs needed to also assimilate different information and formulate their own knowledge scheme of science teaching (Lederman & Lederman, 2015).

Both expanding the knowledge scope and formulating individual knowledge schema require capability and disposition that are as important to PSTs as exploratory skills and passion to science learners (Davis & Krajcik, 2005; Lotter et al., 2007; Penuel et al., 2011). SPI, as an alternative to direct instruction, is also capable of achieving the two objectives. The spontaneity and accountability of PSTs are important because PSTs might not accept pedagogical theories delivered through direct instruction as much as students might not accept scientific content knowledge delivered in the same way (Wang & Buck, 2016; Windschitl, 2003). On the other hand, it cannot be an abrupt transition from educator-centered to learner-centered knowledge construction. Thus, the SPI approach suggested in this study is a promising means for science PST education. Finally, the progress achieved by the PSTs in pedagogical knowledge through the SPI approach also adds weight to the side of professionalism in teacher education (Cochran-Smith & Fries, 2001), because it indicates that pedagogical knowledge, at least part of it, probably has a propositional nature in that it can be constructed by learners. Correspondingly, PST training programs could consider the balance between telling PSTs how to teach and embedding PSTs in teaching practices for them to think about how to teach.

Limitations and future efforts

With the setting of pre–post comparison, we can make no further conclusions about the necessity of the SPI approach, as we are unsure whether the traditional means can achieve the same progress or whether the PSTs would continue with their professional development regarding science teaching as we have assumed. At this moment, we can only suggest the SPI approach as a candidate alternative for science teacher education. We will continue exploring the SPI curriculum with an experimental study comparing this approach with others and a case study about the longitudinal impact of the SPI curriculum on PSTs after they leave the program and enter their own teaching careers.

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References

Akerson, V. L., Hanson, D. L., & Cullen, T. A. (2007). The influence of guided inquiry and explicit instruction on K-6 teachers' views of nature of science. *Journal of Science Teacher Education*, *18*, 751–772. Springer. doi:10.1007/s10972-007-9065-4

Alake-Tuenter, E., Biemans, H. J., Tobi, H., Wals, A. E., Oosterheert, I., & Mulder, M. (2012). Inquiry-based science education competencies of primary school teachers: A literature study and critical review of the American National Science Education Standards. *International Journal of Science Education*, *34*(17), 2609–2640. doi:10.1080/09500693.2012.669076

Banchi, H., & Bell, R. (2008). The many levels of inquiry. *Science and Children*, *46*(2), 26.

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: Examining the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education*, *45*, 83–93. doi:10.1016/j.tate.2014.09.005

Bell, R. L., Smetana, L., & Binns, I. (2005). Simplifying inquiry instruction. *The Science Teacher*, *72*(7), 30–33.

Blanchard, M. R., Southerland, S. A., & Granger, E. M. (2009). No silver bullet for inquiry: Making sense of teacher change following an inquiry-based research experience for teachers. *Science Education*, *93*(2), 322–360. doi:10.1002/sce.v93:2

Bland, J. M., & Altman, D. G. (1997). Statistics notes: Cronbach's alpha. *British Medical Journal*, *314*(7080), 572. doi:10.1136/bmj.314.7080.572

Brand, B. R., & Moore, S. J. (2011). Enhancing teachers' application of inquiry-based strategies using a constructivist sociocultural professional development model. *International Journal of Science Education*, *33*(7), 889–913. doi:10.1080/09500691003739374

Brown, S. L., & Melear, C. T. (2006). Investigation of secondary science teachers' beliefs and practices after authentic inquiry-based experiences. *Journal of Research in Science Teaching*, *43*(9), 938–962. doi:10.1002/(ISSN)1098-2736

Bybee, R. W., Taylor, J. A., Gardner, A., Van Scotter, P., Powell, J. C., Westbrook, A., & Landes, N. (2006). The BSCS 5E instructional model: Origins, effectiveness, and applications. Unpublished white paper. Colorado Springs, CO: BSCS.

Capps, D. K., Crawford, B. A., & Constas, M. A. (2012). A review of empirical literature on inquiry professional development: Alignment with best practices and a critique of the findings. *Journal of Science Teacher Education*, *23*(3), 291–318. doi:10.1007/s10972-012-9275-2

Carlone, H. B., & Harryson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching*, *44*(8), 1187–1218. doi:10.1002/tea.20237

Cobern, W. W., Schuster, D., Adams, B., Applegate, B., Skjold, B., Undreiu, A., & Gobert, J. D. (2010). Experimental comparison of inquiry and direct instruction in science. *Research in Science & Technological Education*, *28*(1), 81–96. doi:10.1080/02635140903513599

Cobern, W. W., Schuster, D., Adams, B., Skjold, B. A., Muğaloğlu, E. Z., Bentz, A., & Sparks, K. (2014). Pedagogy of science teaching tests: Formative assessments of science teaching orientations. *International Journal of Science Education*, *36*(13), 2265–2288. doi:10.1080/09500693.2014.918672

Cochran-Smith, M., & Fries, M. K. (2001). Sticks, stones, and ideology: The discourse of reform in teacher education. *Educational Researcher*, *30*(8), 3–15. doi:10.3102/0013189X030008003

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Erlbaum.

Cohen, L., Manion, L., & Morrison, K. (2007). *Research methods in education* (6th ed.). New York, NY: Routledge.

Colburn, A. (2000). An inquiry primer. *Science Scope*, *23*(6), 42–44.
Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching*, *44*(4), 613–642. doi:10.1002/(ISSN)1098-2736
Crawford, B. A., Capps, D. K., van Driel, J., Lederman, N., Lederman, J., Luft, J. A., & Smith, K. (2014). Learning to teach science as inquiry: Developing an evidence-based framework for effective teacher professional development. In C. Bruguière, A. Tiberghien, & P. Clément (Eds.), *Topics and trends in current science education* (pp. 193–211). New York, NY: Springer.
Darling-Hammond, L., & Bransford, J. (2005). *Preparing teachers for a changing world: What teachers should learn and be able to do*. San Francisco, CA: Jossey-Bass.
Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational Researcher*, *34*(3), 3–14. doi:10.3102/0013189X034003003
Dean, D., Jr., & Kuhn, D. (2007). Direct instruction vs. discovery: The long view. *Science Education*, *91*(3), 384–397. doi:10.1002/(ISSN)1098-237X
Desimone, L. M., Porter, A. C., Garet, M. S., Yoon, K. S., & Birman, B. F. (2002). Effects of professional development on teachers' instruction: Results from a three-year longitudinal study. *Educational Evaluation and Policy Analysis*, *24*(2), 81–112. doi:10.3102/01623737024002081
Elstgeest, J. (1985). The right question at the right time. In W. Harlen (Ed.), *Primary science: Taking the plunge* (pp. 36–46). London, UK: Heinemann.
Embretson, S. E., & Reise, S. P. (2000). *Item response theory*. Mahwah, NJ: Lawrence Erlbaum.
Feiman-Nemser, S. (2001). From preparation to practice: Designing a continuum to strengthen and sustain teaching. *Teachers College Record*, *103*(6), 1013–1055. doi:10.1111/tcre.2001.103.issue-6
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*(4), 915–945. doi:10.3102/00028312038004915
Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *American Journal of Physics*, *66*(1), 64–74. doi:10.1119/1.18809
Hazari, Z., Sonnert, G., Sadler, P. M., & Shanahan, M. C. (2010). Connecting high school physics experiences, outcome expectations, physics identity, and physics career choice: A gender study. *Journal of Research in Science Teaching*, *47*(8), 978–1003.
Huberman, M. (1995). Networks that alter teaching: Conceptualizations, exchanges and experiments. *Teachers and Teaching*, *1*(2), 193–211. doi:10.1080/1354060950010204
Lederman, N. G., & Lederman, J. S. (2015). The status of preservice science teacher education: A global perspective. *Journal of Science Teacher Education*, *26*, 1–6. doi:10.1007/s10972-015-9422-7
Lederman, N. G., Schwartz, R. S., Abd-El-Khalick, F., & Bell, R. L. (2001). Pre-service teachers' understanding and teaching of nature of science: An intervention study. *Canadian Journal of Math, Science & Technology Education*, *1*(2), 135–160. doi:10.1080/14926150109556458
Lee, O., Maerten-Rivera, J., Penfield, R. D., LeRoy, K., & Secada, W. G. (2008). Science achievement of English language learners in urban elementary schools: Results of a first-year professional development intervention. *Journal of Research in Science Teaching*, *45*(1), 31–52. doi:10.1002/(ISSN)1098-2736
Leonard, J., Boakes, N., & Moore, C. M. (2009). Conducting science inquiry in primary classrooms: Case studies of two pre-service teachers' inquiry based practices. *Journal of Elementary Science Education*, *21*, 27–50. doi:10.1007/BF03174714
Linacre, J. M. (2013). *A user's guide to Winsteps ministep Rasch-model computer programs, version 3.80.0*. Chicago, IL: Winsteps.com.
Lord, T., & Baviskar, S. (2007). Moving students from information recitation to information understanding: Exploiting Bloom's taxonomy in creating science questions. *Journal of College Science Teaching*, *36*(5), 40.
Lotter, C., Harwood, W. S., & Bonner, J. J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching*, *44*(9), 1318–1347. doi:10.1002/(ISSN)1098-2736

Luft, J. A., & Hewson, P. W. (2014). Research on teacher professional development programs in science. In S. K. Abell & N. G. Lederman (Eds.), *Handbook of research on science education* (Vol. II, 889–909). New York, NY: Routledge.

Mavhunga, E., & Rollnick, M. (2013). Improving PCK of chemical equilibrium in pre-service teachers. *African Journal of Research in Mathematics, Science and Technology Education*, *17* (1–2), 113–125. doi:10.1080/10288457.2013.828406

Minner, D. D., Levy, A. J., & Century, J. (2010). Inquiry-based science instruction—What is it and does it matter? Results from a research synthesis years 1984 to 2002. *Journal of Research in Science Teaching*, *47*(4), 474–496. doi:10.1002/tea.v47:4

National Research Council (NRC). (2012). *A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: The National Academies Press.

Osborne, J. (2014). Scientific practices and inquiry in the science classroom. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 579–599). New York, NY: Routledge.

Palmer, D. H. (2009). Student interest generated during an inquiry skills lesson. *Journal of Research in Science Teaching*, *46*(2), 147–165. doi:10.1002/tea.v46:2

Penuel, W. R., Gallagher, L. P., & Moorthy, S. (2011). Preparing teachers to design sequences of instruction in earth systems science: A comparison of three professional development programs. *American Educational Research Journal*, *48*(4), 996–1025. doi:10.3102/0002831211410864

Puntambekar, S., & Hubscher, R. (2005). Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? *Educational Psychologist*, *40*(1), 1–12. doi:10.1207/s15326985ep4001_1

Sadler, T. D. (2006). Promoting discourse and argumentation in science teacher education. *Journal of Science Teacher Education*, *17*(4), 323–346. doi:10.1007/s10972-006-9025-4

Schreiber, J. B., Nora, A., Stage, F. K., Barlow, E. A., & King, J. (2006). Reporting structural equation modeling and confirmatory factor analysis results: A review. *The Journal of Educational Research*, *99*(6), 323–338. doi:10.3200/JOER.99.6.323-338

Schwab, J. J. (1962). The teaching of science as inquiry. In J. J. Schwab & P. F. Brandwein (Eds.), *The teaching of science* (pp. 3–103). Cambridge, MA: Harvard University Press.

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, *15*(2), 4–14. doi:10.3102/0013189X015002004

van de Pol, J., Volman, M., & Beishuizen, J. (2010). Scaffolding in teacher-student interaction: A decade of research. *Educational Psychology Review*, *22*, 271–296. doi:10.1007/s10648-010-9127-6

Wang, J., & Buck, G. (2015). The relationship between Chinese students' subject matter knowledge and argumentation skills. *International Journal of Science Education*, *37*(2), 340–366.

Wang, J., & Buck, G. (2016). Understanding a high school physics teacher's pedagogical content knowledge of argumentation. *Journal of Science Teacher Education*, *27*(5), 577–604. doi:10.1007/s10972-016-9476-1

White, B. Y., & Frederiksen, J. R. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*(1), 3–118. doi:10.1207/s1532690xci1601_2

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

Windschitl, M. (2003). Inquiry projects in science teacher education: What can investigative experiences reveal about teacher thinking and eventual classroom practice? *Science Education*, *87*(1), 112–143. doi:10.1002/(ISSN)1098-237X

Wolfe, E. W., & Smith, J. E. (2007). Instrument development tools and activities for measure validation using Rasch models: Part II–Validation activities. *Journal of Applied Measurement*, *8* (2), 204–234.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry*, *17*(2), 89–100.

Zeichner, K. (2010). Rethinking the connections between campus courses and field experiences in college-and university-based teacher education. *Journal of Teacher Education*, *61*(1–2), 89–99. doi:10.1177/0022487109347671

Appendix

Part A. Exemplary pre and post quiz questions

Target knowledge: Friction	Module 1 pre Which of the following is an example of increasing friction intentionally?	A. waxing skis B. adding grease to gears on a bike C. throwing sand on an icy driveway (right answer, 1 pt.) D. oiling a squeaky door
	Module 1 post Which of the following would increase friction?	A. more speed B. more surface area C. smooth surface D. rough surface (right answer, 1 pt.)
Target knowledge: Questioning	Module 2 pre One day in class, you "accidentally" spilled some water on your desk. After a while, the water disappeared. Nancy noticed it and told you: "The wind blew the water away." a) Is Nancy's statement correct? (1 pt.) Why? (1 pt.) b) If yes, what question can you ask to encourage Nancy to elaborate on her statement? If no, what question can you ask to guide Nancy to notice her misconception? (1 pt.) c) Identify the Bloom's level of the question you asked in part b (1 pt.) Why? (1 pt.)	
	Module 2 post In a summer camp, you took out a can of cola from a refrigerator. After a while, there were water drops on the outside of the can. Jacob noticed that and said: "Look, the can is leaking because there is water coming out." a) Is Jacob's statement correct? (1 pt.) Why? (1 pt.) b) If yes, what question can you ask to encourage Jacob to elaborate on his statement? If no, what question can you ask to guide Jacob to notice his misconception? (1 pt.) c) Identify the Bloom's level of the question you asked in part b (1 pt.) Why? (1 pt.)	

Part B. Exemplary question from POSTT (Cobern et al., 2014)

Ms. Walters wants to start teaching her second-grade students about water movement and bodies of water on Earth; that is, to understand that when rain falls on Earth the water flows downhill into bodies of water (streams, rivers, lakes, oceans), or into the ground. Below are the possible ways Ms. Walters can take to teach this lesson. Please match the appropriate pedagogical method (inquiry or noninquiry) with each way.		
Answers	POSTT category	Inquiry vs. noninquiry
A. Have student groups shape soil into hills and valleys and sprinkle water onto it, but don't tell them in advance what it is about or what to focus attention on. Have them report what they observe happens and suggest if this is similar to anything on Earth.	Open inquiry	Inquiry
B. Project a diagram showing rain falling onto the Earth, and water running downhill to form streams, rivers, lakes, and oceans, with some going into the ground. Then go over each aspect carefully while pointing to it on the diagram, taking questions along the way.	Didactic direct	Noninquiry
C. Tell students that rain falling on the ground will flow downhill to form streams, rivers, lakes, and oceans. Demonstrate this with a model: a large shallow box of soil, shaped into hills and valleys. Students watch as she sprinkles water from the spray nozzle of a watering can, and asks them to notice how it flows downhill to form streams and then ponds.	Active direct	Noninquiry
D. Provide a box of soil at each bench and have groups shape landscapes in it with hills and valleys. Have them suggest what might happen if they sprinkle water on it to represent rain. Then have them try it out, report their observations, and relate that to what happens on Earth.	Guided inquiry	Inquiry

Part C. VNOS-C item analysis

VNOS-C Question #6 (Lederman et al., 2001, p. 509)	Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence, or types of evidence, do you think scientists used to determine what an atom looks like?	
Exemplary answers from the authors (Lederman et al., 2001, p. 516)	More informed views	Evidence is indirect and relates to things that we don't see directly. You can't answer … whether scientists know what the atom looks like, because it is more of a construct.
	More naive views	Scientists can see atoms with high-powered microscopes. They are very certain of the structure of atoms. You have to see something to be sure of it.
VNOS-C grading	More informed answer (1 pt.)	I believe scientists are pretty positive about the structure of the atom. Although there is no way to physically see an atom, I think scientists have drawn conclusions about atoms through experimentation and trial and error.
	More naive answer (0 pt.)	Scientists are very certain about the structure of an atom. Scientists used things like microscopes to discover what makes up an atom.
	Undeterminable answer (?)	They used things that they could help them decide what is in the nucleus. Such as properties, like smell, taste, surroundings, reactions to other things. Yes.

Part D. Theoretical model and item code of science identity (SID) and science teacher identity (STID; Hazari et al., 2010)

Pre	Post	SID items	Factor
Q6A	Q2a	I see myself as a science person	Recognition
Q6B	Q2b	My family sees me as a science person	Recognition
Q6C	Q2c	My friends see me as a science person	Recognition
Q6D	Q2d	My instructor sees me as a science person	Recognition
Q6E	Q2e	I am confident that I can understand science in class	Competence
Q6F	Q2f	I am confident that I can understand science outside of class	Competence
Q6G	Q2g	I can do well on exams in science	Competence
Q6H	Q2h	I understand concepts I have studied in science	Competence
Q6I	Q2i	I can overcome setbacks in science	Competence
Q6J	Q2j	I am interested in learning more about science	Interest
Q6K	Q2k	Topics in science excite my curiosity	Interest
Q6L	Q2l	I enjoy learning about science	Interest
Pre	**Post**	**STID items**	**Factor**
Q7A	Q3a	I see myself as a science teacher	Recognition
Q7B	Q3b	My family sees me as a science teacher	Recognition
Q7C	Q3c	My friends/classmates see me as a science teacher	Recognition
Q7D	Q3d	My mentor teacher sees me as a science teacher	Recognition
Q7E	Q3e	I am confident that I can control disruptive behaviors in a classroom and have students	Competence
Q7F	Q3f	follow classroom rules	Competence
Q7G	Q3g	I am confident in creating an inquiry-based science lesson for elementary aged students	Competence
Q7H	Q3h	I am confident that I understand the organization of the EC-6 Generalist Science TEKS and	Competence
Q7I	Q3i	can align my teaching with it	Competence
Q7J	Q3j	I am confident that I can teach the process skills and attitudes that need to be nurtured	Interest
Q7K	Q3k	within an elementary science classroom	Interest
Q7L	Q3l	I understand science concepts well enough to be effective when teaching them	Interest
Q7M	Q3m	I am passionate about sharing ideas about teaching science with others	Interest
		I enjoy teaching others science	
		Thinking about ways to teach science topics is fun	
		It is interesting to observe/listen to others develop their thinking in science	