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Steps to Opening Scientific Inquiry: Pre-Service Teachers' Practicum Experiences with a New Support Framework

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Abstract This qualitative multiple-comparative case study investigates (1) The reported experiences and impressions of four pre-service teachers (PTs) on practicum placement in four different classrooms (grades 1–9) where a new Steps to Inquiry (SI) framework was being utilized to support students conducting open inquiry; (2) The relative dispositions of the PTs toward conducting open inquiry, as indicated by their core conceptions regarding science, the purpose of education, effective teaching, and the capacity of students. Findings indicate that (1) although there were differences in the experiences of the four PTs, all four had an opportunity to observe and/or facilitate students conducting open inquiry with the SI framework, and after the practicum, all of them reported that they would like to include open inquiry in their own classrooms in the future; (2) one PT already possessed core conceptions indicative of a favorable disposition toward open inquiry before the placement; another altered her core conceptions substantially toward a favorable disposition during the placement; a third altered her conceptions regarding the capacity of students; and one PT maintained core conceptions indicative of a dis-position that was not favorable to open inquiry despite the pronouncements that she would like to conduct open inquiry with students in their own future classroom. Possible reasons for the differences in the responses of the four pre-services teachers to the practicum placement are discussed.

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Introduction

Guiding documents for science education, such as the National Science Education Standards (NSES 1996), the new Next Generation Science Standards (NGSS 2012) in the US, and the Revised Curricula for Science in Ontario (RCSO 2007, 2008), encourage teachers to provide opportunities for students to develop skills and understanding of scientific inquiry practices through planning and conducting more open-ended (Pizzini et al. 1991; Roth and Bowen 1993) and authentic (Roth 1995) investigations. However, such opportunities continue to be rare in classrooms (Harlen and Allende 2009).

Commonly, pre-service teachers (PTs) start out with beliefs and attitudes that impede their readiness to implement open inquiry (Crawford 2007). If they are to follow the recommendations of guiding documents, they need support becoming more positively disposed for implementing open inquiry in their future classrooms. Harlen and Allende (2009) suggest that PTs be provided with practicum placements in open inquiry classrooms led by experienced mentor teachers utilizing effective strategies and frameworks. The present study examines (1) the experiences and impressions of four PTs on practicum placement in open inquiry classrooms where mentor teachers use the Steps to Inquiry (SI) framework and (2) the impact of such placements on PTs' beliefs and attitudes.

Theoretical Background and Literature Review

Open Inquiry Learning

Current ideas for science education reform (RCSO 2007, 2008; Rocard 2007; Tytler 2007; NSES 1996; NGSS 2012) are based on constructivist theories (Piaget 1971; Vygotsky 1978), emphasizing opportunities for student-centered learning wherein students and teacher socially co-construct meaning (Vygotsky 1978) through scientific inquiry (investigation) experiences that are more authentic, open, and student-led.

Scientific inquiry refers to the particular ways of observing, thinking, investigating, and validating that scientists use (AAAS 1993). Authentic scientific inquiry experiences, "…denote forms of engagement that have a … resemblance with what scientists … do in their daily work," (Hsu et al. 2009, p. 481). In open scientific inquiry, students initiate, plan, and conduct open-ended investigations where the teacher has not planned the answer (Pizzini et al. 1991). Scientific inquiry is termed "student-led" when it addresses the students' own questions (Bell et al. 2005). For simplicity, "authentic, open, and student-led" scientific inquiry will be referred to here as "open inquiry".

Efforts to implement open inquiry in classrooms are not new. Authors such as Schwab (1962), later Hodson (1996), and Roth (1995) have argued that to become scientifically literate (DeBoer 2000) and decipher science knowledge claims (Driver et al. 1994), students need opportunities to conduct open inquiry. Others such as

Chinn and Malhotra (2002) argue that open inquiry is necessary to develop the kind of critical and creative thinking that scientists use (Zimmerman 2007) and is thought necessary for solving twenty-first century problems (Haigh 2007). Various studies such as those of Roth and Bowen 1993, Roth 1995, and Lee and Songer (2003) demonstrate that student engagement and motivation for science learning increase when open inquiry is implemented. Recently, Geier et al. (2008) demonstrated that student achievement scores on standardized tests were higher in open inquiry classrooms. Unfortunately, the norm for practical "hands-on" science learning in classrooms remains teacher-directed "cookbook style" investigations (Roth 1994) argued to be of little real value because they are so formulaic (Anderson 2002; Hoffstein and Lunetta 2004).

Teacher Beliefs and Attitudes

Teachers and PTs often report that they feel ill-equipped to support students in open inquiry, (Anderson 2002) and some teachers do not believe that engaging in open inquiry is necessary or important for science education (Bencze et al. 2006). Lotter et al. (2007), like Bencze et al. (2006), suggest a strong association between the fundamental beliefs and attitudes (core conceptions) of teachers regarding education and the kind of scientific inquiry practices they support in their classrooms.

The model of Lotter et al. (2007), developed through empirical studies and supported by the literature (e.g. Hewson et al. 1993; Lederman 1999; Wallace and Kang 2004), proposes four core conceptions indicative of teachers' dispositions toward open inquiry: A. Science, B. The purpose of education, C. Effective teaching practices, and D. Students. In this model, when teachers have a positive disposition toward open inquiry, they: A. emphasize science as a process used to find out about the world (not a body of knowledge to be memorized); B. believe that the purpose of education is to help students develop problem-solving skills (not to amass information); C. believe that effective teaching consists in providing opportunities that encourage independent thought (not in the transmission of information); and D. see students as having a high capacity to think and solve problems for themselves (not as passive learners needing teacher-provided information).

Teacher Preparation

Recent research has focused on how to help pre-service (Crawford 2007), and in-service teachers (Crawford 2000) prepare to facilitate open inquiry in classrooms. One approach provides opportunities to engage in real open inquiry with scientists (Blanchard 2006). However, Blanchard et al. (2009) suggest that the intended transfer rarely occurs.

Another approach creates frameworks and materials, supporting teachers and PTs in open inquiry in classrooms (e.g. Smithsonian/NSRC 2012). When teachers are involved in the development of such materials, they are reported to be particularly useful (Powell and Anderson 2002; Harlen and Allende 2009). Keys and Bryan (2001) identified research into such "modes of inquiry-based instruction that are designed by teachers" (p. 631) as a critical area of research.

Practicum placements are a regular feature of B.Ed. programs in Canada (Falkenberg and Smits 2010). As in other Western countries, PT education in practicum placements is based upon socio-cultural constructivist theory (Vygotsky 1978). PTs' learning is situated in the professional workplace of the classroom where PTs act as 'legitimate peripheral' apprentices to master teachers who act as mentors (Lave and Wenger 1991). Rather than controlling the actions of PTs in a top-down instructional approach, Teacher-Mentors (TMs) facilitate PT learning by providing opportunities that are decided upon following discussion with PTs.

This study focuses on PTs' practicum experiences in classrooms where a teacher-designed support framework for open inquiry called the Steps to Inquiry (SI) framework is being utilized by mentor teachers who have at least 2 years prior experience.

Research Questions

1. What were the experiences and impressions of four PTs on practicum placement in open inquiry classrooms where mentor teachers use the SI (SI) framework?
2. What is the impact of such placements on PTs' dispositions toward open inquiry as indicated by their core conceptions?

The SI Framework

The SI framework was designed by teaching coordinators and teachers in a southern Ontario school board (Pardo and Parker 2010; Rees 2010). Based on the "Inquiry Boards" of Buttemer (2006) and the ideas of Goldworthy and Feasey (1997) and Bell et al. (2005), the SI framework provides a structured approach for teachers to support open inquiry.

The SI framework mediates the transition to open inquiry by *guiding teachers and students* through a *series of interactive diagrams* that *prompt students* to *specific actions*: they make their own observations; ask their own questions; identify variables that can be changed; identify dependent variables that can be measured or observed to determine the effect of a change; phrase their own testable questions; make predictions based on their prior knowledge; address their testable question by writing their own procedures; conduct their own investigations; report their findings to the class; and identify further questions. This cycle of steps (inquiry cycle) take several classes to complete. As students become *more proficient* with leading their own cycles of inquiry, teachers gradually *reduce scaffolding*.

Interactive diagrams are a central feature of the SI framework (see Figs. 1, 2, 3, 4). They depict the way scientific inquiry is initiated and planned, leading to testable questions. Students write ideas on color-coded post-it notes and attach them to positions indicated on the diagrams. Following the prompts on the diagrams, students take actions and move notes to the new positions indicated. For a beginning level class, the diagrams are introduced on posters and the teacher guides the whole class through the steps (see the next paragraph). As students' proficiency increases, they work in small groups using the diagrams reproduced on paper copies.

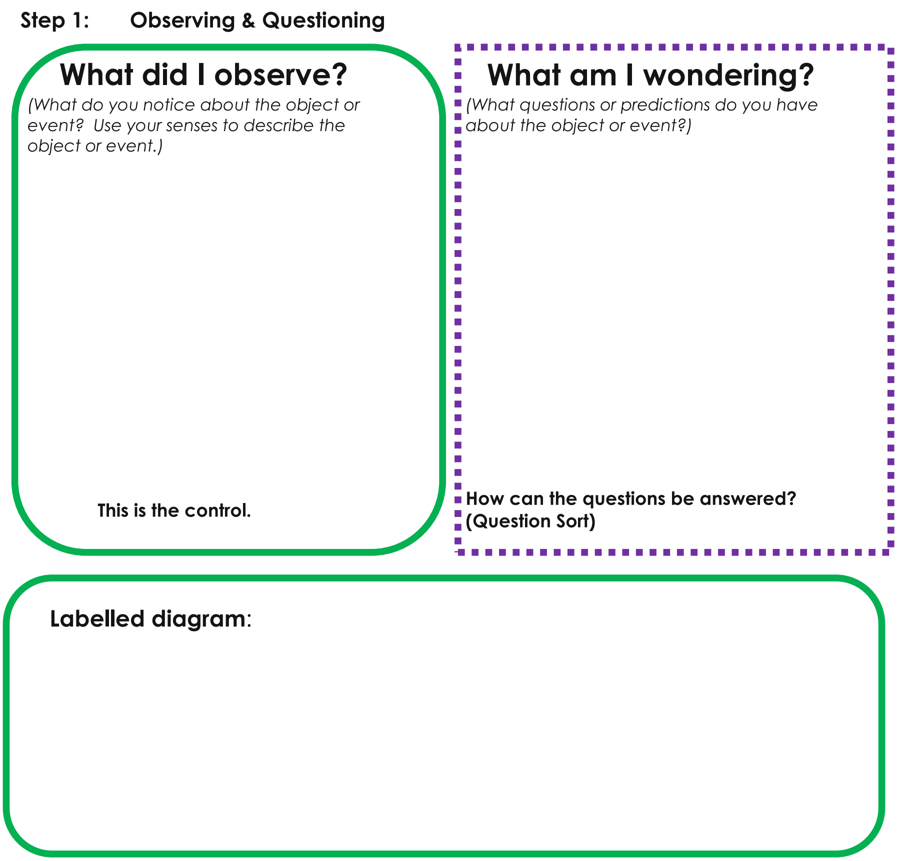

Fig. 1 Steps to inquiry: Planning our investigation (Smarter Science™). Interactive diagram for step 1

The teacher begins with the demonstration of an object or event (e.g. dropping a paper gyrocopter). Students are invited to copy the example and make observations. They write down their *observations*: one on each color-coded post-it note (color A). The notes are collected and placed on the first poster (Fig. 1) under "*What did I observe?"* This includes descriptions of the behavior of the object or event (e.g. the gyrocopter rotates while it falls). Next, the teacher asks the students to write *questions* about the object or event on a different color post-it (color B): one question for each post-it. These questions are placed on the first poster (Fig. 1) under "*What am I wondering?"* Then, the teacher conducts a 'question sort' which identifies questions that could (a) be addressed using science investigation (e.g. "what if the wings were longer?"); (b) be addressed through library research ("why does the gyrocopter spin?"), and (c) those that are speculative and might be addressed through a creative writing project ("how would the world would look if I was riding on the gyrocopter?"). The teacher explains that the students will have a chance to address the library research and speculative questions in future classes.

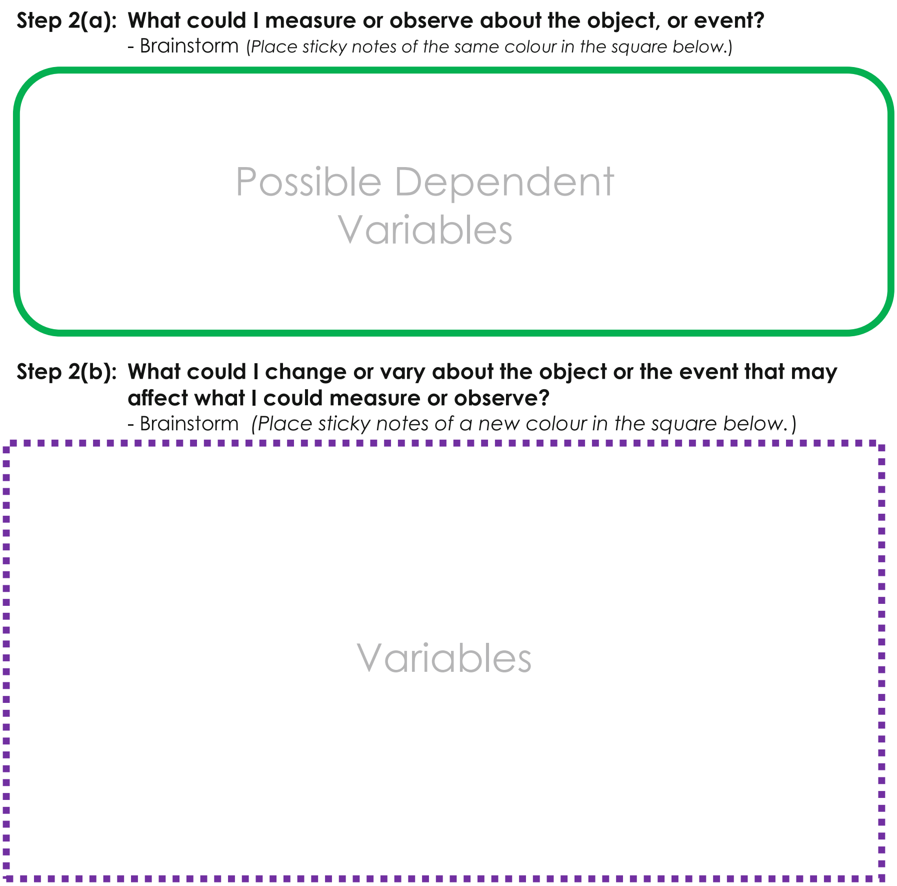

Fig. 2 Steps to inquiry: Planning our investigation (Smarter Science™). Interactive diagram for Step 2

Next, the teacher asks the students for observations (color A) that interest them and that they could measure. These post-it notes are moved from poster 1 (Fig. 1) to the box labeled "Possible Dependent Variables" on the second poster (Fig. 2) (a group might write "the time it takes the gyrocopter to fall to the ground" or "fall time" or "number of turns"). Next, the teacher asks the students to identify things they could change or vary about the object or event that might effect how the object behaves (the dependent variable) and write these on a post-it notes (color B). These are placed on the second poster (Fig. 2) in the box marked Variables (for the gyrocopter example a group might write "wing length", or "number of paper clips").

In Step 3, the teacher chooses as an example one of the possible dependant variables from 2(a) on Fig. 2 to measure/observe and moves that post-it note from 2(a) to the box labeled "Dependent Variable" at the top of the third poster (Fig. 3). Then the teacher chooses as an example one of the student's ideas of something to change from 2(b) on the second poster (Fig. 2) and moves that post-it note to the box labeled "Independent Variable" at the top of the third poster (Fig. 3). For the gyrocopter example the independent or changed variable could be wing length and

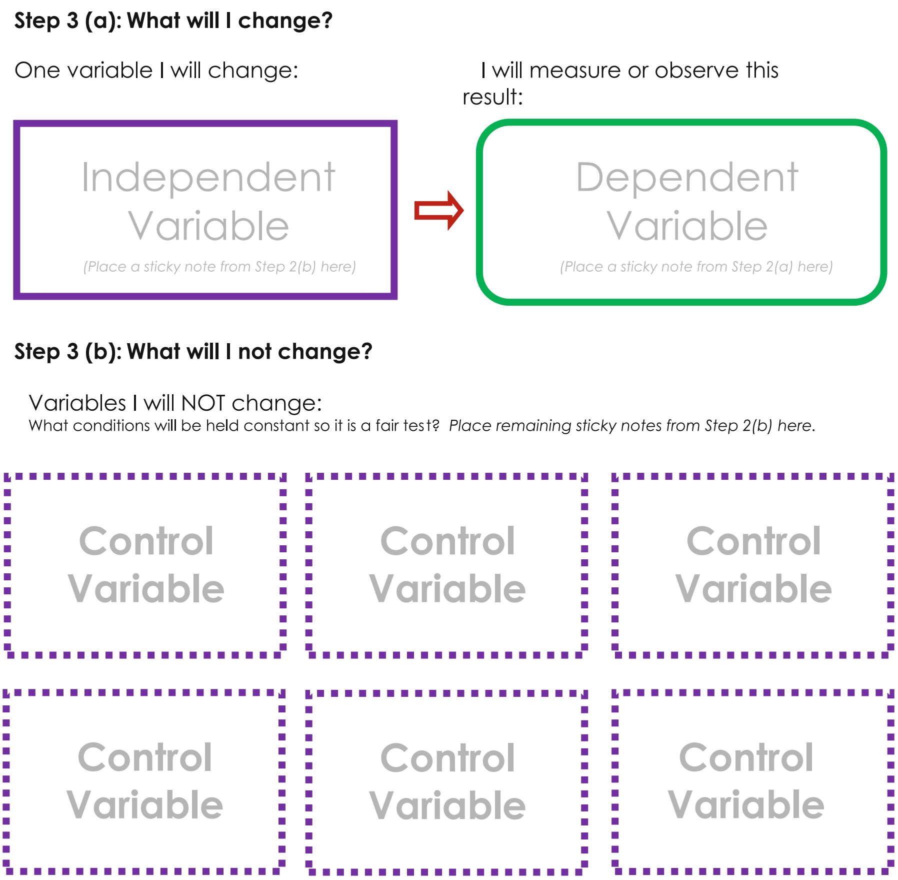

Fig. 3 Steps to inquiry: Planning our investigation (Smarter Science™). Interactive diagram for step 3

the dependent or measure/observe variable could be the time it takes the gyrocopter to reach the ground. The teacher then moves the remaining post-its from the other *Variable* boxes on 2(a) to the boxes labeled "*Control Variable*" on the third poster (Fig. 3). These are the features that must remain constant in the experiment (e.g. if the effect of wing length on the gyrocopter is to be tested, then wing width, number of paper clips, and type of paper must remain constant).

In Step 4, the teacher moves the post-its from the boxes labeled *Independent Variable* and *Dependent Variable* on the third poster to the boxes at the top of the fourth poster in order to phrase the testable question "*If I change this Independent Variable what will happen to the Dependent Variable*" (e.g. "If I change *wing length,* what happens to *the time the paper gyrocopter takes to fall to the ground"*). In Step 5, the students make reasoned predictions about what they expect when they try their experiment.

In the SI framework, further interactive diagrams (not shown) guide the students through the remainder of the cycle of inquiry, including writing their procedures and materials list, conducting their experiment, collecting/graphing data, interpreting results, and presenting them to the class.

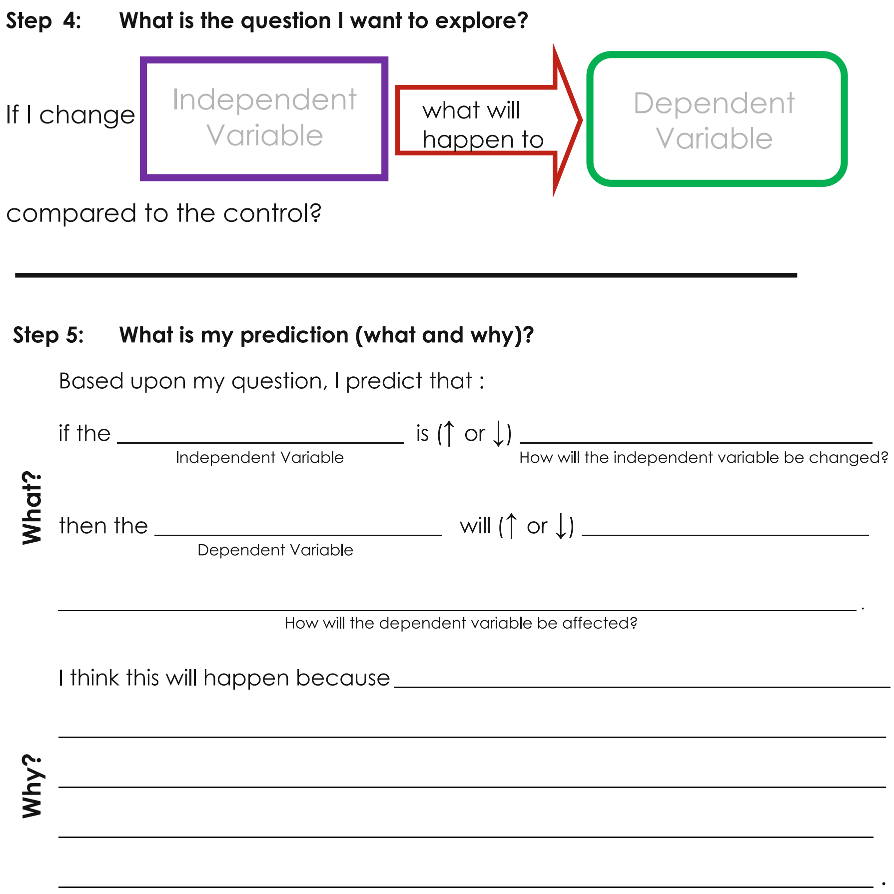

Fig. 4 Steps to inquiry: Planning our investigation (Smarter Science™). Interactive diagram for step 4 and step 5

Methods

Participants

Four PTs, enrolled in a one-year B.Ed. program (science specialists; grades 6–10), participated in the study. They had completed a year-long science-teaching method course wherein they had been introduced to the SI framework, practiced with the framework, and attended a SI framework workshop with the curriculum coordinators involved in its construction. The primary author of this paper was the instructor for the course. Before the study began, the instructor had submitted all marks for the course. These four participants were all who volunteered for an optional practicum placement, after the completion of the course, in classrooms where the SI framework was being utilized. PTs chose the grade level that they would like to work in for the practicum. Details concerning the practicum placement are provided below, under "Context." Pseudonyms are used for the four participants.

Isabelle had a B.Sc. in medical science and an M.Sc. in anatomy. She had experience conducting science research as a B.Sc. honors student and during a summer job. Her practicum was in a grade 1 classroom.

Victoria had a general science degree. She had no experience with science research. Her practicum was in a grade 2 classroom.

Audrey had an honors biology degree specializing in microbiology and had worked for several years in science research. Her practicum was in a grade 7 classroom.

Marie had an honors degree in biology and had worked in a summer job collecting data but had no experience in science research. Her practicum was with a teacher who taught grades 9 and 10.

Context

The study took place after these PTs had completed the year-long science-teaching method course for which the researcher (primary author) was instructor. To avoid any potential sense of coercion to take part, they were invited to participate by a third party so the researcher did not know whether they had agreed to participate until all marks for the course were submitted. All invited PTs agreed to participate.

After completion of the science methods course, PTs had a 2-week practicum to complete for their B.Ed. program. This was an open practicum to be arranged by PTs themselves in any curricular area, at any grade level. Several PTs indicated to the instructor that they would like to experience the SI framework in action in classrooms during this practicum. The instructor offered to arrange practicum placements for any interested PTs. It was late in the year, and most had arranged placements but four/nineteen elected to take this choice.

The science-curriculum coordinators collaborating in the project contacted classroom teachers with at least 2 years experience using the SI framework asking if they would act as teacher-mentors (TM). Science-curriculum coordinators did not hold a supervisory position with respect to the teachers. Their role was one of support/facilitation with the implementation of curriculum. Teachers therefore did not feel coerced to take part. Before the practicum, PTs met with their TMs in a workshop organized by the PI and science-teaching coordinators. Each TM and PT pair worked independently to discuss the area of curriculum that the class would be working on and possible topics from which students could initiate science investigations. The PI and curriculum coordinators did not impose a design for the practicum. The only request made was that the TM provide an opportunity for the PT to learn about use of the SI framework.

Research Design

This qualitative study (Bogdan and Biklen 2003) utilized a comparative multiple case design (Yin 2003) where four cases were considered and compared, each case being a system involving one PT in the context of the classroom, students, and the TM where that PT had their practicum. The study is of an explanatory type (Yin

2003), where the descriptions of PTs' experiences are examined for any possible causal explanations for changes in their core conceptions.

Data Collection

Participant journals were provided to PTs at the beginning of the practicum period and were collected at the end of the practicum. The journals consisted of a series of daily templated pages, each with a space for a record of: description of daily work in the classroom; description of how the SI framework was used; roles played by PTs, TM, and students; and reflection on how their experiences affected their attitudes to open inquiry in classrooms.

Semi-structured interviews were conducted (40–60 min) and audio recorded, with each PT before and following the practicum placement. Core questions (modified from the study of Lotter et al. 2007) focussed on the beliefs and attitudes of participants and included: What is your prior science experience? What do you think are your greatest strengths and weaknesses as a teacher? What do you see as an effective lesson? How do you think people learn science? What do you understand to be a scientific inquiry lesson?

Data Analysis

Recordings were transcribed and journals collected. For the first research question, an account of each inquiry cycle (the cycle of steps using the SI framework that the PT observed &/or participated in within the classroom) was constructed by the researcher through examination of the data collected, relying primarily on data from the PT's participant-journal. The account was checked through discussion with the PT during the post-practicum interview and modified accordingly. The four accounts were compared with respect to three questions: the completeness of the cycles of inquiry; the roles of the PT, TM, and students within the cycle of inquiry; and the manner in which the SI framework was used. For the second research question, PTs' responses to interview questions and their participant-journal entries were examined through the lens of Lotter's model (Lotter et al. 2007). First, data were coded according to which of the four categories were primarily discussed: A. Science, B. The purpose of education, C. Effective teaching practices, and D. Students. Next, a constant comparative method (Bogdan and Biklen 2003) was used to identify themes that emerged within each of these four categories. Then, these themes were examined for alignment with a positive or a negative disposition toward open science inquiry as indicated by Lotter's model (Lotter et al. 2007).

To develop the trustworthiness (Bogdan and Biklen 2003) of interpretations of the data, two approaches were used: 1. Triangulation using multiple data sources. For the first question, semi-structured interviews provided a second source of data for comparison with participant journals regarding the experiences of PTs in classrooms. Specifically, the post-practicum interview provided an opportunity for PTs to further describe the inquiry cycle(s) that they observed and/or experienced in the classroom). For the second question, participant journals provided a second source of data for comparison with semi-structured interviews regarding beliefs and attitudes of PTs. Specifically, using the participant-journal question: “In what ways did your experiences today affect your thinking about doing science inquiry in the classroom?” 2. Member-checking. For question 1, the researcher-generated account of the cycles of framework-supported open inquiry, based on data from a PTs’ participant-journal data, was discussed with that PT during their post-practicum interview. For question 2, a summary of the interpretation of core conceptions, based on the interview data, was shared with participants for comment.

Findings

The purpose of the practicum, that is, the focus of this study, was to give PTs situated classroom experience with the SI framework to guide them in supporting students conducting open inquiry. It was hoped that through this experience they would become more disposed toward conducting open inquiry in their own future classrooms. The practicum came at the end of a science methods course wherein PTs had learned about and practiced with the SI framework and had attended a workshop on the SI framework presented by teachers who had created it.

The study investigates (1) reported practicum experiences of PTs on practicum and (2) the effect of the practicum on PTs dispositions toward open inquiry.

The Practicum Experience

Each PT observed their TM guiding a class through at least one complete cycle of SI framework-supported open inquiry. Each cycle began with students observing an object or event and following through the Steps to Inquiry using the SI framework interactive diagrams (Figs. 1, 2, 3, 4) as described in the introduction. In all cases, the inquiry spanned several days. For example, Victoria reported that the cycle of inquiry she observed took place over 4 days and took 7 h of class time to complete but that this spanned language arts and math time as well as science periods since the cycle of inquiry included expository writing (language arts) and graphing (math). The topic of investigation differed in each of the classrooms. In a grade 1 classroom, Isabelle observed an inquiry of the effect of sunlight, soil, or water on plant growth. In a grade 2/3 classroom, Victoria observed investigations of factors that effect fall time of paper gyrocopters. Audrey observed an investigation of factors that affect solubility rate of sugar cubes in a grade 7 classroom, and Marie observed an investigation of factors that affect the germination rate of soybean seedlings in a grade 9 classroom. In each case, the class was measuring one dependent variable (in Victoria’s example, the fall time of the gyro-copter), and different groups of students were investigating the impact of changing an independent variable of their own choosing (for example, in Victoria’s class, the number of paperclips). In the three elementary classrooms, the inquiry was a cross-curricular activity with Language Arts and Math.

PTs' Impressions

All four PTs reported that they would like to conduct open inquiry, utilizing the SI framework, in their future classrooms. The reasons they gave were (1) the organization and guidance provided by the SI framework, (2) the engagement of the students, and (3) the value of the kind of thinking that the students were encouraged to do. In the next sections, examples from the PTs' journals and interviews relevant to each of these three points will be shared. Findings will be discussed in relation to the literature in the "Conclusions and "Discussion" section of the paper.

(1) All four PTs commented upon the *organization and guidance* that the SI framework brought to the processes of open inquiry. An example comes from Isabelle's participant journal where she made the following comment about her observations in the grade 1 class: "When given the opportunity and the right guidance, students can come up with good testable questions. They can also create action plans … to study these questions. This gives me confidence that (open) inquiry with the SI Framework can really work (if organized really well)"I.P.4.
(2) All PTs described the *engagement* of the students as in the following example from Marie's interview: "they were definitely engaged every morning it was the first thing that they did the bell hadn't rung or anything and they would be getting their seeds every single day—so they were engaged in the activity and I think they had better understanding of why they were doing it" M.P.5.
(3) Audrey and Victoria mentioned the *value of the kind of thinking* that the students were required to do as in the following example from Audrey's journal: "listening to the students' responses, their thinking patterns, and level of engagement in the process confirmed the usefulness of the (SI) framework in developing critical thinking. Students were engaged and actively incorporating and retrieving information, questioning, and creating unique suggestions. The teacher's process toward (supporting) questioning/observing led to an efficient use of time to accomplish the process." A.P.4[1].

Differences in Practicum Experiences

Although PTs shared similar experiences with the SI framework in their practicum placements, differences were also inevitable. The structure of the practicum was based on socio-cultural constructivist theory (Vygotsky 1978) and the idea of professional learning sites as communities of practice (Lave and Wenger 1991). TMs and PTs made decisions together about what would best enable or facilitate PT learning situated within the confines of the particular classroom wherein the practicum took place.

[1] Notation of the examples throughout this section of the paper indicate, from left to right, the first initial of the pseudonym of the PT, P to indicate the example comes from the Participnt Journal and the page number in the journal.

PTs' practicum experiences differed in three important ways: A. the role of the PT, B. the grade level/topic of the inquiry, and C. the teachers and students with whom the PTs worked. These differences will be described in the following section and revisited later in the Discussion.

A. *the role of the PT.* In addition to observing and assisting with a cycle of SI framework open inquiry in their classrooms, Victoria and Audrey acted as the guiding teacher for a second complete cycle of investigation. Victoria guided the grade 2/3 students in her class through an investigation called *Sheep in a Jeep* based on a book of the same title by Nancy Shaw. They investigated the distance travelled by toy jeeps (and sheep) going down a ramp. Different groups changed one variable of their own choosing, such as ramp height, or covering on the ramp. In Audrey's case, her teacher-mentor was responsible for two different grade 7 classes so that Audrey was able to repeat the entire inquiry that her TM conducted but with a different class of grade 7 students. Audrey explained how this repetition was very useful for her learning. "It was very useful to observe a lesson and then try to re-create it as practice—reacting to the students' questions, suggestions for variables etc.—this was great practice at how to accomplish observing/questioning and predicting". A.P.3

Marie and Isabelle did not act as teacher guides for a second cycle of scientific inquiry. Although Marie reported that she had the opportunity to conduct a further inquiry with her class, she indicated that she did not feel confident to take this step and decided instead to conduct more traditional lessons ("I kind of found myself doing things the traditional way a lot—I just wanted things to go smoothly M.P.2"). Isabelle reported that she and her TM decided that observing and assisting through one complete cycle of inquiry with the grade 1 class was the appropriate role for Isabelle to take. Although there is no doubt that leading a second cycle of inquiry would have been beneficial for Marie and Isabelle, the decision regarding the PT's role had to be one that TM and PT decided together.

B. *The grade level/topic of the inquiry.* The practicum placements were at different grade levels, and PTs had different levels of experience with the grade level that they chose for their practicum. This may have impacted PTs' confidence level. For example, Marie chose to work in a grade 9/10 classroom because she wanted to gain this experience but Marie had not taught in a high-school setting before. Isabelle chose a grade 1 classroom, and although she had worked with young children in her tutoring job, she had not taught in a grade 1 classroom before. The PTs also had different levels of familiarity with the topics that students were working on. This was particularly relevant for Marie who was working with grade 9/10 curriculum for the first time.
C. *Working with different teachers and students.* Although all PTs reported that their TMs were excellent and they were very appreciative of the opportunity to work in their classrooms, it is inevitable that many differences existed including the exact manner in which TMs worked through inquiry with their students, and the relationships that they formed with PTs.

PTs Dispositions as Indicated by Their Core Conceptions

PTs dispositions toward including open inquiry were investigated indirectly through examining reported core conceptions in the four key areas (A. Science, B. The purpose of education, C. Effective teaching practices, and D. Students) identified in the model of Lotter et al. (2007). In the following sections, findings regarding PTs' core conceptions before and following the practicum placement will be presented in relation to these four themes.

A. *Science is.*.In Lotter's model, teachers with a favorable disposition toward open inquiry emphasize science as a series of processes (skills of questioning, data collection, and analysis) used to find out about the world, as opposed to a set body of knowledge to be memorized.

In this study, PTs' descriptions of science could be categorized in one of the two ways similar to the two extremes of Lotter's model. The categories are as follows: *science is a series of processes used to find answers to science questions* and *science is a set of concepts to be understood and memorized*. This second category differs from that of seeing science simply as a body of knowledge to be memorized, a view that none of the PTs shared. It is important to note that three of the four PTs described science differently depending on the context of the question. In the context of descriptions of prior *science work* experiences, it was clear that the term *science* for Audrey, Isabelle, and Marie referred to *a series of processes of investigation used to find answers to science questions,* whereas in the context of science learning, *science* referred to *a set of concepts to be understood and memorized*. In this study, we were primarily interested in how PTs viewed science in the context of science learning.

Before the practicum. In the context of questions about science learning, Audrey, Isabelle, and Marie interpreted science to mean primarily a series of concepts to be understood and memorized. For example, Isabelle described science learning primarily as "getting" or understanding the concepts and hands-on activities as something that helped some children with this primary goal ("—the other kids were lost but when they were able to do an experiment they got it. I can get science just by reading and looking at videos but some kids can't do that" I.1.6). Marie recounted examples of her own successful science learning in high school. It was techniques for memorizing that she referred to ("I remember learning glycolysis and she (the teacher) took each step and separated them and then we had to sort them in order and I didn't forget glycolysis after that") M.1.4. Although Marie, Isabelle, and Audrey stated that inquiry was important for learning, they explained it was because it *engaged* students' interest and helped them understand concepts, which was the real goal of science learning.

Victoria differed from the other three PTs; in that, she interpreted the term *science* in the context of *science learning* to mean *a series of processes of investigation used to find answers to science questions.* Victoria's examples of *science learning* came from her early elementary school experiences. She described investigations and problem-solving practices as in the following example: ("The whole school was involved in the Panda Diamond Mystery and everyone had a bag of evidence and each class had to process this evidence and figure out which teacher stole the diamond" V.1.4).

After the practicum. In the context of questions about *science learning*, Audrey changed how she interpreted *science*. Like Victoria, she described science as primarily *a set of processes* and also she described how students could *integrate the two kinds of science learning*: science processes and science knowledge, as in the following example, ("They're observing, they're thinking, they're looking for trends, they're inferring, they're coming up with conclusions and then in order to be able to understand what they're observing they need content (knowledge) to find out whether that make sense." A.2.21–2.22). After, the practicum Marie and Isabelle continued to describe science as *a set of concepts to be understood*.

B. *The purpose of education is*..In Lotter's model, teachers with a favorable disposition toward conducting open inquiry in their classrooms believe that the purpose of education is to help students develop problem-solving skills as opposed to the view that the purpose of education is to amass information. In this study, the PTs comments about the purpose of education could be divided into two categories similar to the opposing categories in Lotter's model: *developing thinking (problem-solving) skills verses amassing concept understanding,*: and one additional category emerged*; helping students feel good about themselves.*

Before the practicum. Victoria described the *purpose of education* to be primarily about encouraging students to *develop thinking skills* as indicated in the following examples: ("(T)o get them to think about things" V.1.7, "(E)ngaging them to think about things and why" V.1.8). Audrey also mentioned thinking skills but she did not emphasize this. A primary theme that emerged from Audrey's pre-practicum interview was *helping students feel good about themselves* as indicated in the following example: ("When they're proud of themselves when they have done a good job at something, when they feel good about being here" A.1.16).

After the practicum. Audrey, like Victoria, strongly emphasized *the development of thinking skills as the purpose of education* as in the following example ("it's really important that they develop that thinking—it's again it's developing that set of thinking skills and that's the most important thing" A.2.26). Neither Isabelle nor Marie mentioned the development of thinking skills as the *purpose of education* before or following practicum, instead they described the *development of concept understanding*. For example, Isabelle stressed that she wanted her students to "get" science as indicated in the following example (One of my students, he can't get it so I'm trying to help him" I. 1.6).

C. *Effective teaching practices are*..In Lotter's model, teachers with a favorable disposition toward conducting open inquiry in their classrooms believe that effective teaching is *providing opportunities* and *encouraging* students to be *independent learners and develop independent thought*, as opposed to the *transmission of information to students.* In this study, PTs' views of effective teaching three categories emerged. One was similar to Lotter's model; encompassing *encouraging and guiding the development of student thinking* *and independent learning* the second encompassed *being organized and prepared and well planned,* and the third *engaging the students' interest.*

Before the practicum. It was only Victoria who focused on *encouraging and guiding students to think independently and become independent learners* as a priority for effective teaching, for example, when talking about encouraging the students to come up with their own solutions to problems: (Coming up with different solutions—and some of the stuff they come up with … it's so creative what they do" V 1.9). There were two different kinds of *guidance* described as part of effective teaching. In the first, the teacher guided with an idea in mind of where she wanted the students to go; in the second, the teacher supported the students without knowing where their interests would lead. Before the practicum, Audrey only mentioned the first kind of guidance as in the following example: ("If I can sort of seize the moment or direct their thoughts and help them along—if I can direct that toward what I'm supposed to be teaching them" A.1.17).

After the practicum. Victoria and Audrey focused on *encouraging and guiding students to think independently and become independent learners* and Audrey explained that she had 'shifted her mindset'. In her descriptions of the teacher's role, she focused on the second kind of guidance where the teacher supported the students without knowing where their interests would lead, ("to guide (the students) along as best I can without taking away that power from them to be able to construct that knowledge for themselves" A.2.4). It is this second form of guidance that best fits with Lotter's model of a teacher with a positive disposition toward open inquiry. Before and after the practicum when discussing effective teaching, Marie and Isabelle focused on *being organized and prepared*, as seen in this example from Marie: (You have to consider what questions you want to ask them to (help) their understanding". M.1.2). Isabelle described the amount of preparation she had done to make a lesson successful in the following example: ("(the) experiment with science levers (was) my associate teacher's idea that I pulled off because I did a lot of preparation" I.1.10). Victoria and Audrey also mentioned this theme. All four PTs mentioned the importance of engagement. For example, when Isabelle was describing a teacher she admired, it was the teacher's ability to read or know his students and respond to their needs by coming up with activities that they *found really engaging* that she liked: ("He could come up with an activity in his head and the kids would really enjoy it and it would be something that I would never have thought of" I.1.8). Marie echoed this theme when she described an effective lesson ("Planning something students can really relate to" M.1.9).

D. *Students* are..In Lotter's model, teachers who engage students in open inquiry see students as *capable and evolving problem-solvers*, as opposed to teachers who perceive their students as *passive learners needing teacher-provided information.* In this study, PTs comments on the capacity of students were divided into three categories: *students have a low capacity and need lots of help*; *students have diverse capacities*; *students are more capable than expected.*

Before practicum. Victoria indicated her *belief in the high capacity of students* when she described a discovery-style activity that she conducted with her class for a unit on light. ("The students said "okay listen, let's find out what is transparent and opaque" and from there they just took the material and did their thing to figure it out") V.1.17. Audrey was concerned to *help* students before the practicum. Before the practicum, both Marie and Isabelle described the *diversity of capacity among students* when they were responding to a question about how children learn science. Both described the best students as those who could learn simply by listening, reading, and watching videos, and they identified themselves in this group. For example, Isabelle compared herself and her own ability to that of a student ("a little guy in my grade 3 class—can just get it by looking at pictures and words …"I can get science just by reading and looking at videos and what not but some kids can't do that" I.1.6). Marie explained that she also learned by "listening to her teacher" but noted that "this is not the case for everyone". M.1.4

After practicum. Victoria explained how the students *exceeded her expectations* when they were conducting their open inquiry investigations. ("I didn't think that they would be able to do it—I was, there's no way they could pull it off, they're only in grade 2 and then they just blew me out of the water with the walking around—Oh we already know about variables, we're just going to change this one and those ones are going to be the same and yeah they're our unchanged variables. You're how old? Seven Miss. Okay you know more than me right now" V.2.26). Audrey explained that during the placement, she struggled with developing her belief in the students' capacity to figure things out for themselves. She explained how she felt when she observed her TM helping students by allowing them to correct errors for themselves ("I just so wanted to go around and point things out to them and he just really let them do it all wrong and then they had got to do it again—boy, you know it was really hard to let them do it wrong" A.2.24). She explained that she herself had been a student who liked to follow direction and that part of her new mindset on teaching that she developed through her practicum was that she had come to realize that when students are learning, it is really important for them to have the teacher believe in them and allow them to figure it out for themselves. Audrey stated that ("it's okay for them to struggle, which is my new mantra." A.2.23). After practicum, Isabelle also described how the students exceeded her expectations ("I didn't think it was going to work, like grade ones are hard to reign in and to actually get them to think science other than just making them do something, I was, oh it's not going to work. They really enjoyed it and they're invested in it 'cause it was their idea" I.2.4). Before and after the practicum in the context of a variety of questions, Marie talked about students' *low capacity and need for help*. When talking about her concerns regarding leading open inquiry, Marie explained: ("I've experienced kids needing their hand held a lot, you know? And when everyone is working on something different, you can't really hold everyone's hand" M.1.22). After the practicum in the context of the same topic, she explained in the following examples: ("I would put step-by-step on the board what to do and they'd still ask me what to do next—so I just—I don't think they're ready (for open inquiry)" M.2.8. "I'm not sure what it is but they need to just constantly ask me what to do so it would be harder to do an inquiry-based lesson when they're just always looking for what I want them to do" M.2.8 "The trouble with these grade nines is that I would give them a pice of paper with all the instructions on

Table 1 Pre-service teachers' dispositions to open science inquiry before and after the practicum, as indicated by their core conceptions (Lotter et al. 2007)

Pre-service teacher	Core conceptions—alignment with positive disposition to open inquiry							
	Science		Purpose of education		Effective teaching		Students	
	Before	After	Before	After	Before	After	Before	After
Victoria	✔	✔	✔	✔	✔	✔	✔	✔
Audrey	–	✔	–	✔	–	✔	–	✔
Isabelle	–	–	–	–	–	–	–	✔
Marie	–	–	–	–	–	–	–	–

them and they'd still ask me what to do M.2.8 "You need a flow chart of what to do next otherwise they're just constantly asking you "What do I do next" or saying "I don't know what to do" M.2.8).

Conclusions and Discussion

All four PTs in this study described the SI framework as an effective tool for supporting enactment of open inquiry. The two main reasons given were that students were highly *engaged* by open inquiry and the SI framework helped the teacher maintain *organization and guidance*. Engaging students' interest and being *organized and prepared* were two themes that emerged as important to all PTs conceptions of effective teaching. In a previous study of enactment of Project-Based Science learning (Marx et al. 1994), *fostering engagement and involvement* while *maintaining order* were demonstrated to be important issues for teachers. Powell and Anderson (2002) make the point that teachers need tools to help them enact open inquiry in the real situation that classrooms present, "…rhetoric and recommendations are not enough to change real classroom practice". Teachers find such tools most useful when teachers are involved in their creation (Harlen and Allende 2009). This study demonstrates the potential of the SI framework for general use in supporting teachers enacting open inquiry.

Although the PTs reported that they *would like* to implement open inquiry using the SI framework, Crawford (2007) suggests that such desire is not enough. In her study of PTs' *enactment,* she found that, "there are many mediating factors that will influence the actual outcome" (Crawford 2007). A strong predictor of *actual practice* in Crawford's (2007) study and in a study by Lotter et al. (2007) was PTs beliefs and attitudes about science, teaching, and learning. For this reason, we examined PTs' *core conceptions* before and following the practicum through the lens of Lotter's model that focuses on four key areas: A. Science, B. The purpose of education, C. Effective teaching practices, and D. Students.

We found that PTs core conceptions were affected to different degrees by the practicum (Table 1). After the practicum placement, Audrey shifted her core conceptions in all four areas to become more positively disposed to open inquiry.

Victoria's core conceptions indicated that she was already positively disposed toward inquiry before the practicum placement. Isabelle's core conceptions became more aligned in one of the four areas (D. belief in the capacity of students). However, after the practicum Marie's core conceptions remained unaligned in all four areas.

The reported differences in PTs practicum experiences could explain these findings. It is possible that if Isabelle and Marie had practiced as well as observed a complete cycle of SI framework-supported open inquiry, they would have altered their core conceptions and become more disposed toward open inquiry. Perhaps if Marie had worked with at grade level more familiar to her she would have felt more confident to try a second cycle of inquiry.

However, another source of variation that could explain the findings is the strength of the initial core conceptions that PTs possessed before the practicum placement began. Marie was strongly committed to her belief that the students she encountered did not have the capacity to conduct their own investigations. Even after she observed them conducting investigations and exhibiting engagement regarding their investigations of soybean seedling growth, Marie continued to hold this view. If the students did not follow instructions in a *teacher-directed* investigation, Marie wondered how they could be expected to plan and conduct their own investigations. However, Roth et al. (2008) suggest that it is the freedom to *actually plan their own investigations* that gives students the impetus to *get involved and interested*. "Students lost themselves in the projects of their own design and, at all stages, lost track of time, always astonished that their scheduled class time was up when the bell rang." (Roth et al. 2008, p. 2)

Audrey reported that her mindset had been shifting over the course of the year, and it was the practicum that brought everything together for her ("my mindset has been changing through the whole year and I think this timing of this last 2 weeks has really done a lot to sort of cement, to really reinforce to me—the importance of the student to teaching"). We believe that with more exposure and practice with SI framework-supported inquiry, Marie and Isabelle would also make this shift in thinking.

In a study of the effectiveness of professional development programs that placed teachers in science laboratory settings to develop understanding of the processes of science first hand, Blanchard et al. (2009) found that the experiences of teachers did not transfer to their classrooms and did not result in them developing more open inquiry opportunities for their students. The findings reported here suggest that one effective way to help teachers become more disposed toward including open inquiry in their future classrooms is to give them a practicum placement with a teacher mentor experienced with SI framework-facilitated open inquiry in his/her classroom.

Although the sample size is small and more evidence is needed, the study suggests that the practicum experience should be long enough to allow the PT both an opportunity to view at least one complete cycle of inquiry *and* an opportunity to practice leading a class through at least one additional cycle of inquiry him/herself.

The study leads to additional important questions regarding the nature of the practicum experiences with the SI framework. For example: How does SI framework-supported inquiry compare with existing accounts of open inquiry in other settings? In what different ways do teachers use the SI framework in their classrooms ? Current research involves analysis of video recordings of framework-supported open inquiry to address these questions.

An unexpected finding in this study was that the student (Victoria) with the *least* experience of science research was most positively disposed toward open science inquiry before the practicum. In contrast, the PTs in our study with *most* science research experience (Audrey and Isabelle) were not positively disposed toward open science inquiry before the practicum. These findings differ from those of Windschitl (2002) who found that all three high school teachers in his study who used inquiry frequently in their classrooms had prior long-term experience with authentic science inquiry in a professional context. Melville et al. (2008) found that individuals with extensive experience of science inquiry at the university level or in the professional world appeared most capable of deploying open inquiry. Victoria's comments suggest that it was her own *early schooling* that had impacted her views. To the best of our knowledge, no studies have been conducted to determine the influence of *science inquiry experience in elementary school* on the dispositions of PTs toward open inquiry. This would be an additional interesting study to conduct.

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