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Reflections of a First-Year Chemistry Teacher: Intersecting PCK, Responsiveness, and Inquiry Instruction

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Abstract: Many educators agree that science instruction should be dominated by inquiry strategies, while others stress the need for responsive practices to place a focus on student learning and understanding. Some scholars believe the two approaches exist on opposite ends of an instructional spectrum, while others believe they may be aligned and intertwined. Pedagogical content knowledge (PCK), the broadly accepted gold standard for science education, seems to include both. Understanding how teachers incorporate inquiry strategies and responsiveness and how the two intersect could lead to a more complete framework for K–12 science instruction and help streamline science teacher education. This qualitative single-case study examined the reflections of a first-year chemistry teacher by exploring how she demonstrated responsiveness to students while maintaining a teaching orientation of inquiry-based instruction. Results indicated that responsiveness depended on a high level of PCK and led to higher or lower levels of inquiry based on the students' need for teacher support. Additionally, findings showed that the teacher's stated and demonstrated beliefs about inquiry were disconnected. Finally, a gap between science conceptual understanding and mathematics PCK suggested the need to support more innovative mathematics pedagogical strategies during physical science teacher education.

Keywords: adaptive strategies; inquiry science instruction; pedagogical content knowledge; responsive teaching

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1. Introduction

The adoption of the Next Generation Science Standards (NGSS) changed the landscape of K–12 science instruction by concentrating on scientific literacy and thinking and acting like a scientist [1]. The new standards reinforced the ongoing evolution of science education over the last few decades from lecture and text-based approaches to the use of inquiry, leading to a shift in the instructional emphasis from the teacher as a moderator to the teacher as a facilitator [2,3]. Successful application of inquiry-based methods allows teachers to focus on student understanding rather than simply transferring knowledge, moving educators from a behaviorist approach to a more constructivist view of learning. This type of practice allows students to construct meaning and actively understand content. Inquiry involves developing scientific knowledge using science process skills and critical thinking creatively applied to traditional science content [4]. The NGSS includes scientific and engineering practices to develop scientific knowledge, establishing inquiry methods as a significant component of science education. Thus, most educators support the notion that K–12 science instruction should be dominated by inquiry strategies.

Alternatively, some scholars believe that the focus on student learning and understanding scientific concepts transcends the method or strategy for teaching and places the utmost importance on responsive practices that promote agency. While exercising responsiveness, a teacher must recognize, interpret, assess, and respond to students' ideas and support them in sensemaking [5,6]. Another interpretation of responsiveness proposes the idea of adaptive strategies to effectively navigate the variable environment of classrooms, requiring teachers to pedagogically adjust to student needs in the moment [7,8]. Whether focusing on supporting sensemaking or adaptive strategies, responsive teachers must utilize diligence and draw on high levels of teacher knowledge to develop abilities to engage students' evolving ideas. These teachers view learning as an active process on the part of the learner and may utilize their pedagogical reasoning to make the needed instructional adjustments.

Responsive-minded scholars are concerned that teachers may not fully engage in these adaptive processes when focusing primarily on methods. However, to be responsive to students, a teacher must have a deep understanding of content and reasoning skills with a high degree of dexterity in pedagogy. This tradition of responsive teaching exemplifies the wisdom of teachers' practice called for by educators with a framework of teaching for understanding [9]. Consequently, centering instruction around student learning rather than teaching methods requires a teacher to attain a high degree of professional knowledge and skills.

The gold standard for science teacher knowledge and skills is pedagogical content knowledge (PCK). In the 1980s, Shulman [10,11] sought to describe a type of professional knowledge specific to teachers that separated them from content specialists. He envisioned PCK as the teacher's content knowledge deconstructed, intertwined with pedagogy, and reconstructed for optimal student understanding. In his work, Shulman placed PCK alongside content and pedagogical knowledge, knowledge of the curriculum of learners, educational contexts, aims, purposes, and values within a teacher's knowledge base. This type of teacher knowledge is a complex construct with collective and personal dimensions and topic specificity [12]. At the collective level, inquiry methods are generally considered best practice for most topics in science; however, at the personal level of PCK, teachers must be able to respond to the needs of individual students and make adjustments to instruction [13]. As a result, responsiveness is considered integral to developing high levels of PCK [14]. Considering Shulman's pioneering work, most scholars in science education today regard well-developed PCK as essential for teachers to effectively promote student content understanding.

The emphasis on a deeper understanding of and ability to perform practices supports the NGSS goal of developing a scientific mind through scientific practices and experiencing science as a scientist. Nevertheless, many educators disagree on the relative importance of inquiry and responsiveness. Some scholars believe inquiry methods and responsive practices exist on opposite ends of an instructional spectrum, while others believe these approaches may be more aligned and intertwined than once thought, and the broadly accepted benchmark of PCK seems to include both [15]. Nonetheless, instructional focus, whether inquiry methods or responsive teaching, and the degree to which educators develop PCK could significantly impact the connections between science instruction and student understanding, the future state of K–12 science education, and the level of scientific literacy in the United States.

Understanding how teachers incorporate inquiry strategies and responsiveness and how the two intersect could lead to a more complete framework for K–12 science instruction and help streamline science teacher education. To explore the nuances involved in the interactions of teacher knowledge, instructional approaches, and responsive teaching practices, I examined the reflections of a novice first-year chemistry teacher by exploring how she demonstrated responsiveness to students while maintaining a teaching orientation of inquiry instruction. The following questions guided the study:

(1) How does a novice first-year chemistry teacher describe her responsive teaching practices, and how do they impact her implementation of inquiry instruction?
(2) What patterns emerge around responsiveness, inquiry, and topic-specific pedagogical content knowledge (PCK) during the implementation of several chemistry lessons?

2. Theoretical Framework

Experiential learning provides the foundation for the theoretical approach to this study. Specifically, I utilized the Lewinian Model of Experiential Learning, as described by Kolb [16], as a theoretical framework. This model, shown in Figure 1, includes the integrated processes of concrete experience, observations and reflection, the formation of an abstract concept, and applying that concept as a new experience. This four-stage progression forms a learning cycle grounded in observing and reflecting on a here-and-now experience. Further action results from the internal analysis and reflection on data collected during the event. The process is based on personal experience as the origin of the abstract concept and the medium through which to test it. Therefore, feedback loops become an autonomous vehicle for learning.

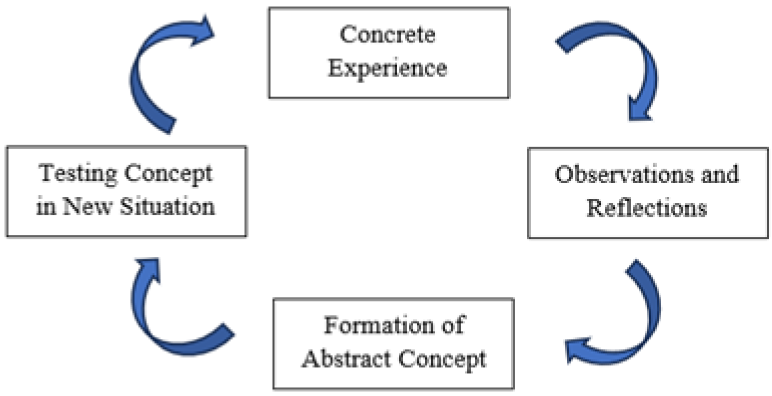

Figure 1. The Lewinian Experiential Learning Model, adapted from [16].

This experiential learning model exemplifies the subjective nature of the teaching experience within the learning context [16]. Since teachers adjust classroom experiences according to student engagement, questions, thoughts, and understandings, the entirety of a lesson cannot be preplanned. Teachers must prepare to assess and respond to student participation during classroom activities. Lehane [17] links this type of teaching and learning to teachers' personal PCK, indicating the need for subjectivity in responding to individual learners. Thus, based on the teacher's individual PCK, feedback loops within the concrete teaching experience provide the teacher with the opportunity for responsive practices. The experiential learning theory provided a lens to view the knowledge and practices of the chemistry teacher as she responded to students and reflected on instruction during this study.

3. Review of the Literature

3.1. Inquiry Instruction in Science

Inquiry instruction promotes the NGSS goal of scientific literacy through knowing and doing science and has become the dominant approach to K–12 science education in response to the changing position of science in society. Following the recent explosion of advancements in science and technology worldwide, the body of knowledge for each science discipline grew much too large for teachers to be "keepers" of knowledge. Science education can no longer be considered a body of scientific facts transferred to students through lecture-style methods. The need arose for students to learn how to make sense of phenomena, connect to other disciplines and topics, and utilize practices authentic to real-world scientists [18,19]. Consequently, more innovative instructional approaches were adopted, such as inquiry incorporating scientific practices. Inquiry instruction in science refers to "the pedagogical decisions and actions that teachers make to promote scientific practices such as asking testable questions, creating and carrying out investigations, analyzing and interpreting data, drawing warranted conclusions, and constructing explanations that promote a deep conceptual understanding of fundamental science ideas" [20] (p. 62). During the development of the NGSS [1], one of the scholars' primary goals was to define science and engineering practices and clarify their relationship to science instructional methods. Wilcox et al.'s [20] preceding definition of inquiry aligns with the scientific practices identified by the NGSS and supports the goals of deeper scientific understanding.

3.1.1. Impact of Inquiry Instruction

Science education research supports using inquiry-based instruction to enhance student understanding of science content in K–12 classrooms. Studies suggest that inquiry-based instruction positively impacts student understanding of science content and helps students construct core scientific concepts to achieve goals such as improving scientific thinking and understanding the nature of science [1,3,4]. Other studies indicate that inquiry-based science programs improve student achievement and attitudes and enhance practical skill acquisition, such as developing higher-order thinking skills [21,22]. Furthermore, inquiry-based education reinforces the NGSS goal of scientific literacy by emphasizing its importance in developing understanding, competencies, and attitudes needed in technology-based societies [23].

Inquiry teaching methods are generally considered the most effective approach to teaching science, and many researchers find that student learning depends on authentic inquiry experiences. Wei and LeSage-Clements [24] supported this notion by highlighting the need to nurture an inquiring mind, seek depth of understanding, and emphasize experience-based learning as key themes underlying effective inquiry-based science instruction. Studies collectively suggest that the inquiry approach can positively impact student understanding of science content in K–12 science education. Even so, according to 25. Areepattamannil et al. [25], student efficacy in science shows benefits from a combination of inquiry and teacher-directed methods. But what does research say about the efficacy of specific inquiry-based strategies on a large scale?

More comprehensive studies have become possible because of the advent of large-scale international assessments like the Organization for Economic Cooperation and Development's (OECD) Programme for International Student Assessment (PISA). Oliver et al. [26] addressed the efficacy of inquiry-based instructional methods by comparing 15-year-old students' scientific literacy and the association with the instructional strategies they experienced across six OECD countries participating in PISA in 2015. The elements of inquiry, as envisioned by PISA creators, include opportunities for students to explain their ideas, spend time in the laboratory doing practical experiments, have class debates about science questions, draw conclusions from experiments, and design experiments to test their ideas [26]. Findings across the six countries showed that students who reported consistently experiencing high frequencies of inquiry strategies in their classrooms evidenced lower levels of scientific literacy. The data also showed a strong positive association between students' scientific literacy and the frequency of teacher-directed and adaptive teaching strategies. Additionally, the study showed that correlations vary between students' scientific literacy and different components of inquiry. For example, a negative linear relationship existed between scientific literacy and higher frequencies of class debates and scientific argumentation. However, for doing practical experiments and drawing conclusions from them, students benefited at moderate rather than low or high frequencies.

On the surface, this might seem to indicate the limited effectiveness of an inquiry approach and contradict the results of previously mentioned studies. However, a closer look at Oliver et al.'s [26] findings revealed significance for the level of teacher guidance and frequency of strategies during inquiry instruction. On average, the most substantial scientific literacy performance was associated with students who reported they experienced specific inquiry strategies in some rather than most or all lessons. On average, students reporting using inquiry in most or all lessons achieved considerably lower levels of scientific literacy. Therefore, Oliver et al. [26] found a complex pattern of relationships between students' scientific literacy and inquiry strategies. Additionally, they found that proper teacher guidance and student prior knowledge were the most significant factors necessary for success. Students had higher outcomes when they had adequate prerequisite content understanding and sufficient guidance from the teacher based on their [the students'] level of knowledge and skills. Hence, the seemingly inconsistent data representing the efficacy of inquiry instruction may be addressed by the variations in the approach itself.

3.1.2. The Continuum of Inquiry Practices

The term inquiry may appear to indicate a single approach; however, it may be implemented using a range of more guided, to more open methods. The inquiry cycle includes asking testable questions, designing and carrying out investigations, analyzing and interpreting data, drawing defensible conclusions, and fashioning explanations that support a deep understanding of scientific content [20]. These methods vary depending on who determines the question, the procedure, and whether the student knows the outcome. The more teacher-centered the method, the lower the level at which it is considered. On the contrary, the more student-centered the method, the higher the level of inquiry in the instruction [17]. Figure 2 shows this continuum of inquiry methods. Although guidance from the teacher exists on the lower end of the continuum, it is a necessary component of inquiry instruction [26]. Many of these strategies require teacher scaffolding and support as students begin using the practices.

Confirmation Inquiry.	Structured Inquiry	Guided Inquiry	Open Inquiry
Question given by teacher	Question given by teacher	Question given by teacher	Question derived by learner
Procedure given by teacher	Procedure given by teacher	Procedure developed by learner	Procedure derived by learner
Outcome known in advance	Outcome not known in advance	Outcome derived by learner	Outcome derived by learner
Very teacher-focused	**Less teacher-focused**	**More learner-focused**	**Very learner-focused**
Low level ⟵	⟶		**High Level**

Figure 2. Continuum of Inquiry Methods, adapted from [17].

According to Kirschner et al. [27], the benefit of teacher guidance only begins to decline when students have a level of prior knowledge sufficient to provide "internal" guidance. Although Kirschner has been a critic of inquiry methods and called for more direct approaches to science instruction, his point has merit, according to the Oliver et al. [26] data. Students require sufficient prior knowledge and teacher support as they move to higher levels of inquiry instruction. The degree to which teachers assess student knowledge and scaffold their learning can significantly affect student outcomes from inquiry in science classrooms. Thus, the significance of understanding the issues impacting inquiry instruction and the need for effective frameworks and strategies to support its implementation in K–12 science education are apparent in the current educational climate.

Educators worldwide consider inquiry-based instruction as "best practice" for promoting students' interest in and understanding of science. Still, inquiry-based science instruction is not without its challenges. Many teachers face difficulties in enacting inquiry teaching, including appropriate guidance, time management, and deficiencies in inquiry instructional techniques. Still, other teachers' mental images of science inquiry and inquiry teaching reveal limited representations of specific science and engineering practices [28,29]. These shortcomings emphasize the importance of teachers' knowledge and skills to support inquiry-based science exploration and create a culture of inquiry in the classroom.

3.2. PCK and Classroom Practice

Shulman [10,11] began the focus on teacher knowledge and skills and proposed PCK as a synergistic compilation of teacher knowledge bases to produce a specialized form of knowledge. He considered PCK necessary for teachers to teach effectively. He envisioned it as the ability for a teacher to go beyond just knowing the content but also having the ability to deconstruct the content and reconstruct it, mixed with pedagogy for optimal student understanding. Shulman [10] stressed,

> Teachers must not only be capable of defining for students the accepted truths in a domain. They must also be able to explain why a particular proposition is deemed warranted, why it is worth knowing, and how it relates to other propositions, both within the discipline and without, both in theory and in practice.
>
> (p. 9)

In other words, teachers must deeply understand the content and its connections to the natural world and the society in which they live. At the heart of Shulman's quest to define teacher knowledge was the goal of improving the teaching profession and, in turn, enhancing respect for teachers [11]. Most scholars in the field of science education agree that high levels of PCK are necessary for teachers to effectively support student content understanding, and that inquiry represents the collective "best practice" approach for science instruction [30].

Although PCK is topic-specific, the majority of science educators opt for an inquiry mindset and adopt inquiry strategies for most science topics. Nevertheless, embedded within personal PCK is the need for teachers to understand learners' interests, abilities, and difficulties while simultaneously determining what areas of the content students have mastered and in what areas they need guidance and support in [13]. Teachers must then adjust their pedagogical strategies in response to the needs of students during instruction. As a result, responsiveness is considered integral to developing high levels of PCK [14]. Inquiry may seem to exist at one end of a spectrum of educational thought, focusing on the importance of teaching methods. But Rudolph [3] explains that "methods of inquiry are highly contextual, contingent, and emergent over time" (p. 3). This view of inquiry instruction suggests a subjective nature to the approach and places it within the learning context in the realm of more personalized forms of PCK.

3.3. Responsive Teaching

Responsive science instruction goes beyond curriculum and methods and places the teacher's focus on student thinking and reasoning. During instruction, teachers listen to what students say, interpret clues in their reasoning, and adjust instruction accordingly [5,6,31]. Since responsive teachers demonstrate a continual awareness of how students are progressing and take time to hear their ideas during the lesson, they may gauge student understanding and adjust instruction to meet collective and individual student needs. As a result, science instruction can adhere to the intent of the NGSS and contribute to the engagement of all students in science learning [5,6,31]. Additionally, responsive teaching methods constitute a shift from fragmented science concepts to connections among scientific ideas through student sensemaking. By connecting ideas, students gain a broader understanding of overarching science concepts and acquire the ability to know how to learn science rather than just recalling scientific facts [5]. Therefore, scientific and engineering practices, included in the NGSS, are at the heart of understanding how to learn science and help form the foundation of responsive science teaching practices.

Much of the research on responsive practices addresses cognitively guided instruction and how teachers notice student thinking in mathematics education [32]. These studies emphasize the effectiveness of the designated methods of research. However, they involve predetermined frameworks, and many are set in professional development settings. Discursive and case study research, on the other hand, provides a more nuanced view of responsive methods within classroom interactions. Much of this work is accomplished by coding teacher comments and follow-up questions and ranking them from low to high responsiveness [33,34]. This type of research, however, requires much time for analysis as the grain size of the data occurs at the teacher utterance level. Additionally, as with cognitive-based research methods, *a priori* frameworks are needed for analysis [35]. These studies approach responsiveness from a deductive perspective, which could limit the uncovering of nuance within the practice.

On the contrary, studies using a more inductive approach examine instruction and seek the emergence of responsive moments from the data, where researchers must identify and characterize evidence of responsiveness [35]. For example, during a lesson, a teacher may directly incorporate a student's idea or wondering into the lesson or abandon his/her lesson plan altogether in response to students' thinking, readiness, or level of comprehension. This type of analytical approach uses a more adaptive instructional lens to view teaching as an activity comprising both knowing and doing. Thus, complex professional teaching practice is not the implementation of prescriptive behaviors but the ability to make knowledgeable pedagogical decisions that change in response to the learning context [10]. According to Allen et al. [36],

> Adaptive teaching in science, technology, engineering, and mathematics (STEM) is a process that teachers initiate when they recognize and gauge their students' STEM-related conceptual development, inquiry processes, and real-world connections and then maneuver their instruction to further develop these features of students' learning. An adaptive teacher may engage in this process during planning, while teaching, or after teaching.
>
> (p. 217)

Researchers have proposed that adaptive teachers effectively transverse the complex and irregular environment of classrooms [7]. Hatano et al. [8] describe this practice as adaptive expertise, suggesting that it requires teachers to innovate at the moment. Teachers must utilize diligence and draw on high levels of PCK to develop abilities to engage students' evolving ideas. These teachers view learning as an active process on the part of the learner and may utilize their pedagogical reasoning to make the needed instructional adjustments.

From a responsive teaching perspective, instruction should be dynamic and not rely on scripted lessons. However, this idea exists in tension with the need to train and support teachers in implementing science instruction. The resulting best practices and techniques are often touted as the benchmark for successful implementation of K–12 science instruction [15]. Further, research supports the value of specialized inquiry methods for impacting student outcomes by utilizing variations in frequency and degrees of teacher support. Consequently, responsiveness may be assumed to exist on the other end of the educational thought spectrum, opposite from inquiry methods, and the two may seem mutually exclusive. However, some scholars suggest that the two-work hand-in-hand [15]. Responsiveness supports inquiry through the development of student thinking, and the techniques utilized in inquiry instruction are the tools teachers use to elicit and respond to students' ideas. This study aims at examining the relationship between responsive teaching practices, inquiry techniques, and the degree to which teacher knowledge influences their interactions with one chemistry teacher. Highlighting these connections within the practice of one teacher may reveal nuances in the studied relationships and support researchers in the design of future investigations. Insight from examining the interactions between responsiveness, inquiry instruction, and PCK could ultimately impact teacher preparation and teacher professional development for science instruction.

4. Materials and Methods

This research employed a narrative, single-case study approach to provide a comprehensive view of the responsiveness of one early-career chemistry teacher in a real-world setting. By using the narrative reflections of the chemistry teacher, I intended to make her pedagogical choices, the reasoning behind them, and the connection to inquiry instruction more visible [37,38]. Consequently, I used an experiential learning perspective to delve into the knowledge of and reasoning behind the teacher's actions [16] and applied an inductive approach to account for the personal and contextual nature of responsiveness and teacher knowledge. Although generalizable results are not possible from a single case, understanding the nuances within the responsive practices of one teacher could provide a necessary step toward identifying underlying themes to be explored on a larger scale.

4.1. Background and Context

The case was bounded by Annie, a novice chemistry teacher in her first year of teaching at a new high school in a large district in north Texas. Annie excelled in her undergraduate classes, including science and education topics. She did her field experience at a local high school and strove to engage students using inquiry-based lessons. However, her cooperating teacher used mostly lectures and did not utilize inquiry-based instruction. As a result, Annie was not supported in the methods she learned in her teacher education program while participating in her field experience. Annie began her first year and valued the prospect of the upcoming district-based support, but found herself in the lead role of her chemistry teacher group when the experienced teacher left on maternity leave early in the school year. Therefore, Annie decided to continue working with a coach with whom she had built a trusting relationship while completing her teacher education.

This project was part of a broader investigation into the development of PCK for a first-year chemistry teacher. The more comprehensive study proposes to investigate how a university-based coach could use mediated reflection to encourage knowledge development for the teacher. The process included weekly, one-hour Saturday coaching sessions during the spring of the school year. These sessions involved planning, viewing recorded lessons and reflections, and mediating reflections on instruction. Here, I focus on a subset of the data, including the teacher's video reflections following each instructional implementation and recorded mediated reflections during coaching sessions. These reflections provided insight into the knowledge and responsiveness of the teacher and her instructional mindset during the process. The research goal was to better understand the relationship between Annie's responsiveness and PCK within the context of her classroom, given her orientation toward inquiry instruction.

4.2. Data Collection

Data for this exploration focused on reflections from dual implementations of five chemistry lessons from two separate units of study. Table 1 shows the six big ideas presented for the lessons; however, it is essential to note that Annie combined Big Ideas E and F and taught them in the same lesson. Thus, six big ideas appeared in five different lessons. To gather data, Annie taught each lesson, immediately sat down with a camera, and recorded a short testimonial-style reflection of her teaching and learning experience. She uploaded the recordings to a drive she shared with her university-based coach. The coach watched the reflections before each coaching session. During the sessions, the coach discussed the reflections with Annie and mediated additional reflections to help her interpret student actions and reactions and make connections at a deeper level. The reflections following lesson implementation and those recorded during coaching sessions provided data for analysis.

Table 1. Big ideas for five recorded lessons.

Label	Big Idea	Initial PCK Score
Big Idea A	The mole concept	53
Big Idea B	Gas law stoichiometry	43
Big Idea C	"Like dissolves like"	38
Big Idea D	Types of solutions	38
Big Idea E	Molarity	37
Big Idea F	Dilutions	34

4.3. Data Analysis

The primary focus of this research was to explore the relationship between teacher responsiveness and inquiry instruction in light of the teacher's topic-specific PCK. Therefore, the data analysis was framed around these three themes. The analysis began by taking transcripts of Annie's reflections and identifying strands of responsiveness. The adjustments to her lessons determined each strand during and between implementations and when planning for future instruction. Since the data resulted from Annie reflecting on her teaching immediately following implementation and during coaching sessions, first-hand observations of student-teacher interactions were not used for analysis. Annie's account of student thinking and understanding and her responses to them comprised the data set representing her instructional moves. Therefore, I addressed responsiveness using an adaptive strategy approach [7], analyzing pedagogical adjustments as evidence of teacher responsiveness. In addition to the accounts of lesson events, reflections offered insight into Annie's mindset during her in-the-moment teaching experiences. This insight was valuable for understanding the pedagogical reasoning behind the adaptations.

Next, Annie's adaptive moves were aligned with the inquiry cycle. For this analysis, I defined the components of inquiry instruction to include asking testable questions, designing and carrying out investigations, analyzing and interpreting data, drawing defensible conclusions, and fashioning explanations [20]. Additionally, teacher-pedagogical moves were examined using the continuum of inquiry instruction shown in Figure 2. Reflections on adaptations to instruction were aligned to the inquiry cycle and then positioned along the inquiry continuum. Then, Annie's responsive strands were coded using open coding followed by axial coding to develop themes and reveal patterns within the data.

Finally, although PCK was a vital component of the data interpretation, it was not directly included in the data analysis but was calculated as part of the broader study, which included planning documents, content representations (CoRes), and recorded coaching sessions for planning, collaboration, and reflection [39]. CoRes provided an instrument for Annie to record her understanding of big ideas and the best way to teach them [40]. She completed CoRes and provided planning documents for each big idea to be taught, and reflected on her teaching of the same big ideas as a pre-service teacher. Then the researcher determined Annie's PCK within the refined consensus model (RCM) for each big content idea [39]. The RCM consists of the collective, personal, and enacted forms of PCK and emphasizes the interactions among them. Annie's CoRes and reflections provided insight into her pedagogical decisions impacting her personal and enacted forms of PCK.

During that analysis process, an adapted form of the PCK Essentials Rubric, shown as Figure 3, was used to calculate scores [39,41]. The rubric contained 15 items, each scored on a Likert scale from 1 (not adequate) to 4 (in-depth knowledge), and allowed the breakdown of teacher knowledge into its various forms, which aligned well with the different levels of the RCM. Annie's PCK was determined before the initial lesson implementation and after coaching and the final lesson implementation to provide a glimpse into the process of PCK development. Nevertheless, this study did not focus on teacher knowledge development but used the PCK scores to determine patterns and correlations with inquiry and responsiveness. The adaptive instructional moves were dependent on her knowledge and skills during lesson implementation. As a result, the initial PCK score for each big idea shown in Table 1 represented Annie's PCK for the present analysis.

PCK-Essentials Rubric		
CK	PK	PCK
1) Has content knowledge to promote students' conceptual understanding/help students learn the content.	6) Transforms content knowledge to effective teaching and learning.	11) Blends the content knowledge and the pedagogical strategies on how to teach the content.
2) Uses questions that enable the learner make sense of the concepts.	7) Knowledge and understanding of students' thinking and learning processes.	12) Displays confidence in understanding of the content as a content specialist that distinguished the from the pedagogue
3) Makes connection with other ideas, real life experiences, and provides the learner with meaningful experience that leads them to know the concept.	8) Knowledge of effective classroom assessment.	13) Uses effective assessment to guide the teaching for students' learning of specific goals and ideas.
4) Displays a repertoire of effective teaching strategies based on the conceptual understanding of the subject	9) Integrate and use activities that address the needs or demands within a given classroom context.	14) Enhances teaching by producing meaningful learning and expected outcome.
5) Chooses innovative materials for teaching the concept.	10) Knowledge of internal or external factors that influence classroom instruction.	15) Provides overall effectiveness and flexibility for both the teacher and learner.
(Abell, 2008; Anderson & Freebody, 2012; Ball, Thames & Phelps, 2008; Baumert et al., 2010; Findell, 2009; Shulman 1986, 1987)	(Findell, 2007; Voss, Kunter, & Baumert, 2011; Shulman, 1986, 1987)	(Abell et al., 2009; Loughran, Berry, & Mulhall, 2006; Loughran et al., 2012; Okonlawon, 2010; Shulman 1986, 1987; Sunal et al. 2016)

Figure 3. PCK Essentials Rubric [39] adapted from [41].

5. Results

During this study, I set out to understand how a first-year chemistry teacher demonstrated responsive practices, how those practices impacted her inquiry instruction, and how these two ideas related to her PCK levels for each big idea. To investigate this, I focused on (a) how Annie adapted her instruction in response to student thinking and understanding and how this impacted her inquiry practices and (b) how her adaptations of instruction and inquiry practices related to her teacher knowledge and skills.

5.1. How Does a Novice First-Year Chemistry Teacher Describe Her Responsive Teaching Practices, and How Do They Impact Her Implementation of Inquiry Instruction?

Using the inquiry cycle and continuum of inquiry instruction, the deductive analysis of the adaptive instructional reflection threads revealed findings relating Annie's responsiveness to her use of inquiry strategies. Annie made instructional adaptations for four of the six big ideas, including Big Ideas A, B, C, and D. Her adaptations occurred during and between implementations and when reflecting forward in planning for future implementations. When considering the inquiry continuum, Annie made adaptations from very student-focused to more student-focused, toward more teacher-focused, and one adjustment during direct instruction, which was not on the continuum. She did not adapt instruction for Big Ideas E and F; one lesson remained very student-focused, and the other was implemented using direct instruction and not on the continuum. Table 2 summarizes Annie's adaptations for each lesson, the timing of the response, her relative PCK score, student reactions to adaptations, and the shift on the inquiry continuum.

Table 2. Annie's Responsiveness to Students for Big Ideas A–F.

Big Idea (PCK/60)	Response/Adaptation	Timing of Response	Student Reaction	Movement on Continuum
A (53)	Began the second lesson with the driving question about the piece of aluminum foil	Between Implementations	Increased engagement	Away from very student-focused
	Did not require all students to use the packet/let them focus on the aluminum foil from the driving question/provided an application/extension using a magnesium strip for the independent groups.	During 2nd Implementation	Student thinking visible Student questions driving investigation	Toward more student-focused
	Begin the lesson with the aluminum foil, have them guess how many atoms are in it, and brainstorm how to figure it out	For Future Implementations	NA	Toward more student-focused
B (43)	Began the 2nd lesson by explaining the mole map (Direct Instruction)	Between Implementations	Increased engagement	Not on continuum
C (38)	Allowed flexibility in stations	Between Implementations	Increased engagement	Toward more student-focused
	Gave clearer instructions/added a printed procedures for students to take to lab/put data chart on the board	Between Implementations	Increased engagement	Toward more teacher-focused
	Class worked collectively to develop a hypothesis before entering the lab	Between Implementations	Student thinking visible	Toward more student-focused
	Planned to create an inquiry lesson for the future	For Future Implementations	NA	Toward more student-focused
D (38)	Did not get to the lab but had students collectively write the procedure during the 1st and 2nd lesson	During Implementation	Increased engagement Student thinking visible	Toward more student-focused
E (37)	Guiding students through developing concentration formula by thinking aloud	Kept Guided Inquiry Strategy	Student thinking visible	Remained highly student-focused
F (34)	Worked mathematics problems	Direct Instruction	Confusion	Not on continuum

Annie shifted instruction toward more student-focused practices when adapting lessons during implementation and for future lessons. But, when she adapted between implementations, she demonstrated more response variation. One adaptation was away from very student-focused, two were toward more student-focused, one was toward more teacher-focused, and one was during direct instruction, which was not on the continuum. Instructional adaptations resulted in increased engagement, making thinking visible and student questions driving the investigation. While implementing Big Ideas E and F, Annie did not make adaptations. However, for Big Idea E, instruction remained very student-focused, and students remained engaged and continued to make their thinking visible. For Big Idea F, instruction remained direct and not on the continuum, and students continued to show confusion. Key reflections provide detailed accounts of how and why she responded to students.

Key Reflections Adaptations. Below are two key reflections Annie made following her implementations after making adaptations in response to students' thinking and understanding:

> **Big Idea A.** Annie: In fourth block, I added the driving question. And so, they were actually more engaged and interested in trying to figure out how many atoms were in the piece of foil. They were trying to figure out how to do it and do research. And they were thinking about "I know this mass on the periodic table is the mass of an atom. So, if we figured out the mass of the foil, we could, you know, like divide it." And so, they were actually trying to figure it out.
>
> I had a couple of students who are working independently and just kind of flying through it. And then I had a group at the back that was just really interested in figuring out the answer to the foil question. So, I didn't make them do the whole packet. I showed them how to figure out the number of atoms in the piece of foil. And then I gave them a strip of magnesium from the prep room. And they figured out how many atoms were in that.

> It seemed like the driving question and having an actual, "By the end of this class, you're going to answer this question" and a genuine application for what they were learning helped keep them be more engaged. It gave them more purpose for what they were doing in the lab.

Annie adjusted her lesson from a packet-driven to a more student-focused inquiry lesson during the second implementation of the Big Idea A lesson. She also supplied a driving question for the students. Annie engaged students and had them collaborate, think aloud, and find purpose in the lesson. She demonstrated moving away from a very student-focused inquiry for this big idea by supplying them with a driving question. However, she also adapted during the second implementation by eliminating the packet for some students and extending the lesson with the addition of a magnesium strip. This response aligned with a shift toward higher levels of inquiry.

> **Big Idea D.** Annie: So, we didn't actually get to lab, but we wrote the procedure for it. I don't know. I think they got the point. I think I care more about them actually thinking through the procedure and getting that skill rather than weighing things out and dissolving things because we did that. We've done that now multiple times. I didn't get everything done that I had wanted to, but that's okay.

> Annie adjusted her lesson from conducting a teacher-focused lab to supporting students in writing a procedure during the first implementation of the Big Idea D lesson. She scaffolded students through the process and supported them in building skills aligning with the NGSS scientific practices. For this big idea, responsiveness led to higher levels of inquiry.

5.2. What Patterns Emerge around Responsiveness, Inquiry, and Topic-Specific Pedagogical Content Knowledge (PCK) during the Implementation of Several Chemistry Lessons?

The inductive analysis revealed two major themes. Table 3 provides examples of codes, categories, and the resulting themes of teacher beliefs and knowledge from the analysis. First, findings indicated that teacher beliefs played an important role in Annie's rationale and ability to adapt lessons in response to students. However, there were some discrepancies between Annie's stated beliefs and the demonstration of her beliefs. Annie indicated her belief that inquiry instruction promotes higher levels of student understanding. She professed to value student learning above the need for stringent teaching measures and lesson completion. However, several times during her reflections, she expressed frustration when adapting her instruction to higher levels of inquiry, even though it was in response to the needs of the students. She also shared her disappointment when she could not complete a planned lesson but adapted to support students in developing inquiry skills.

Table 3. Examples of codes, categories, and themes.

Examples of Narrative Codes	Categories	Themes and Subthemes
We created a collaborative hypothesis before the lab so it would flow better, looked back at hypothesis after lab, discussed and corrected thinking. I didn't get everything done I wanted to, we didn't actually get to the lab, I care more about them getting the skill, they were intrigued, I wanted them to make the connection, I kept reminding them to do the packet, it scaffolded everything for them to get to the answer, The packet told them exactly what to do, and I gave them the resources, I didn't really like the lesson because it needs to be more inquiry, It was very inquiry based so they needed to do a lot of discussion, We did the first two together, so I didn't think I was asking a lot, I put a data table up on the board with the six substances that they were testing	Teaching focus Learning focus Lesson completion mindset Inquiry promotes understanding Conducting investigations emphasis Hands-on equals inquiry More scaffolding is better	Teaching Beliefs *Stated Beliefs* *Demonstrated Beliefs*
I don't know if that was the best way to do it, It was very confusing, They are not actually separating when they dissolve, I don't remember doing that in school, I was not as confident with that idea, It was very inquiry based [we were just dissolving salt in water], Students were initially engaged in the lesson but then got confused during calculations, but it took me a minute to figure it out, We got the math out of the way in one day, They didn't make the connection because it was math on more math	Science content Science pedagogy Mathematics content Mathematics pedagogy Mathematics/Science connections	Teacher Knowledge *Competence* *Self-Efficacy*

Key Reflections Beliefs. Following are a few key reflections representing the discrepancy between Annie's demonstrated beliefs and her stated belief that inquiry instruction is more valuable than teacher-directed methods for student learning:

> **Big Idea A**. Annie: They were actually more engaged and interested in trying to figure out how many atoms were in the piece of foil. I kept having to remind them to do the packet. I kept reminding them that the packet was a scaffold.
>
> **Big Idea C.** Annie: It was very painful. So, we did a little hands-on lab and discussed expectations before it the lab. I kind of did it with stations. Each one had a different substance that they were going to test to see if that was soluble in water. Since it was very inquiry-based, I have to discuss in order for them to get anything out of the lesson. And they just weren't interested in discussing. When we tried to have group discussions, they really weren't giving a lot of input.
>
> The second time, before the lab started, I did put a chart, a data table up on the board with the six substances that they were testing the solubility of. We did a hypothesis before to see if they already knew if they were soluble or not. And we made a hypothesis as a class before we went in the lab and tested them. Afterward, we looked back at the hypotheses that we made and corrected anything that needed to be corrected. The lesson went better, but it wasn't a better lesson.
>
> **Big Idea D.** Annie: So, today's lesson went [pause] not bad, but not good. I didn't get everything done that I had planned. So, we didn't actually get to the lab, but we wrote the procedure for it. So, I don't know.

Although Annie responded to students by shifting the lesson toward a more student-focused inquiry for Big Idea A, she still focused on reminding them about the packet for a while. She struggled to let go of her need to strictly follow the teaching agenda. For Big Idea C, Annie adjusted her lesson to include having the class collectively form a hypothesis before going into the lab and revising it following the investigation. However, she was not happy with the level of discussion during and after the lab. She did not see the full value of developing the skills of hypothesis creation and revision but remained frustrated that they did not implement the lab and dissolve the salts in water. Finally, for Big Idea D, Annie adjusted her lesson and supported students in writing a procedure. Still, she was very disappointed that they did not carry out the lab even though she stated that she was more concerned about them developing the skill of procedure writing.

Second, findings indicated that teacher knowledge played an important role in Annie's rationale and ability to adapt lessons in response to students. Annie showed higher levels of PCK for big ideas, where she had strong content knowledge. She tended to opt for more student-focused inquiry techniques when confident with the science and mathematics content. However, when she struggled to adapt instruction, she tended to show lower content knowledge and low self-efficacy with the content and ways to teach it. Additionally, Annie had difficulty adjusting instruction involving mathematics concepts. Mostly, she used direct instruction techniques, and she found it more challenging to respond to students when they struggled with the mathematics and when she struggled with it herself. During these times, she found it difficult to relate the science concept to the mathematics teaching.

Key Reflections Knowledge. Following are a few key reflections representing the struggles Annie faced with selecting science concepts, implementing mathematics instruction, and connecting science concepts to mathematics teaching:

> **Big Idea B.** Annie (1st implementation): Ok, so I just finished doing first block. It was a mess. I did not do a good job of explaining. I didn't do the mole map, like I said I wanted to. Or go over it at least. And I feel like they were all confused at the same time, and so I couldn't help everybody. And it was just [pause] not good. Yeah. Yeah. I was thinking about the question they kept asking me about where to start the calculations. "What should I do first?" I didn't really get to

over the mole map thing. I had copies of it on the lab tables for them to use, but I think I need to spend more time on the fact that the mole is the middleman. And maybe I need to go over the mole map and walk them through how to use it.

Annie (2nd implementation): They still did not love Gas Law 'stoic,' but I do think it made it a little bit easier for them to see the actual path. So, they could see how they were connected. Even if maybe, they didn't necessarily know why you would use both. But they could see the connection and it gave them a pathway. So, like it wasn't like every single problem they had to start from scratch and figure out what to do. They started to see the pattern and used it as a tool. The first group didn't have that tool, so they were kind of like all over the place.

Big Ideas D, E, F. Annie: I never really remembered learning about solutions that much in my own chemistry class. And so, I didn't have a good understanding of the scope that I needed to go in to and specifically what I needed to teach. Whereas solutions, I feel like there's more wiggle room for how in-depth you go and how much you want them to know about everything. Like when I was writing these two paragraphs to summarize the unit, I kept moving things around and taking this out and putting it down here because there's so many different sequences you could teach it. Since everything's kind of intertwined. So, I was having trouble figuring out the best logical way to go. It's like you're on a circle and at what point on the circle do you start? I think I just needed a better understanding of the overall end goal so that I could plan the activities better.

Big Idea E. So, I had two pitchers of Kool-Aid. One of them was the correct recipe and one of them was twice the amount of Kool-Aid powder and sugar needed for that specific volume of water. And so, I started out with questions about the difference between the two. Will they taste the same? What's different about them? And so, I just kind of led them to the fact that one of the solutions is more concentrated. Then I asked them, "How do you think concentration is calculated?" And they were actually able to pretty much tell me the, the formula without knowing the units. They knew that it was a ratio of solute to solvent. And so, I added that molarity is moles to liters. And then we calculated the molarity of what Kool-Aid should be if you follow the recipe correctly. And then we calculated the molarity of what the stock solution or the one that I had made super concentrated was.

Big Idea F. It made sense that we know the concentration, so what do I need to do to get it from this high concentration to the one that I want it to be at. Although the drawback is that the $M_1V_1 = M_2V_2$ formula is kind of confusing. It took me and the other teachers like a minute to figure out, okay, what number goes where? And I still have to really think about it. Since I think of it like that, we have our current concentration, and we don't know what volume it needs to be to make the other one. Or maybe it's the other way around.

The higher Annie's content knowledge and self-efficacy in the science concept and its connection to the mathematics concept were, the more she was able to make responsive adaptations to student understanding. Nonetheless, she did not teach mathematics through inquiry-based instruction. The one exception was the part of the final lesson addressing Big Idea E. Her knowledge of the connections between science and mathematics content was high. She used student-focused inquiry strategies but did not make adaptations to the lesson because students had high levels of engagement and understanding. The lesson broke down when she incorporated Big Idea F. She was uncomfortable with the mathematics of this concept and unsure of how to teach it.

6. Discussion

This study aimed to add nuance to the relationships between PCK, inquiry instruction, and teacher responsiveness. Specifically, I intended to shed light on the interconnectedness of inquiry strategies and responsive practices. Critics that focus on best practices question whether methods-based mindsets overemphasize prescriptive processes and neglect the importance of student thinking and ideas in the development of student understanding [5,15,27]. However, responsiveness seems to support inquiry instruction. Teachers respond to students' ideas to develop their autonomy in inquiry-based practices, and the skills utilized in inquiry are the tools teachers use to elicit and respond to students' ideas.

Moreover, PCK seems to further bridge the two by connecting collective inquiry strategies and personal responsiveness. Findings from Annie's reflections seem to support Kavanagh et al.'s [15] assessment that inquiry and responsiveness are not on opposite ends of an instructional spectrum, nor are they mutually exclusive. On the contrary, Annie responded to students with increased inquiry strategies whenever possible. Still, subtleties found in the data of this study reveal relationships supporting Oliver et. al's [26] results from the 2015 PISA data, stressing the necessity of teacher guidance and the importance of frequency for the implementation of inquiry strategies. The following discussion of results addresses the first research question about how Annie demonstrated her responsive practices and how they impacted her inquiry instruction. Annie made multiple responsive adaptations to her instruction; many shifted toward the more student-focused area of the inquiry continuum. She responded to student engagement, thinking, and questions during these adaptations.

For Big Idea A, during the second implementation, she did not require all students to use the packet. She let groups working independently focus on the aluminum foil from the driving question. She provided an extension for these groups, having them apply their understanding using a magnesium strip. This response allowed students to think aloud and implement components of the inquiry cycle, such as designing and carrying out investigations and drawing defensible conclusions. When discussing the lesson for future implementations, she said she would begin the lesson with aluminum foil, have them guess how many atoms are in it, and brainstorm how to figure it out. Her future lesson would be much more student-focused inquiry by design. For Big Idea C, during the second implementation, the class worked collectively to develop a hypothesis before entering the lab and revised it following the completion of the lab. Annie's students could ask a testable question, analyze and interpret data, draw defensible conclusions, and fashion explanations. Again, she planned to create an inquiry lesson for the future. For Big Idea D, Annie did not get to the lab but had students collectively write the procedure during the first and second lesson implementations. These adaptations responded to student needs and shifted to more student-focused inquiry forms.

Annie also made multiple responsive adaptations to her instruction that did not shift toward the more student-focused area of the inquiry continuum. For Big Idea A, she began the second lesson by providing the driving question about a piece of aluminum foil. This adaptation represented a shift away from a student-focused inquiry. For Big Idea C, Annie added printed procedures for students to take to the lab and put a data chart on the board. Although these adaptations shifted toward a lower level of inquiry, they were based on the guidance needed by the students and confirmed Oliver et al.'s [26] findings, stressing the importance of appropriate teacher support during the inquiry. Annie's students needed guidance and scaffolding until they reached the level of knowledge and skill necessary for independent work.

The following discussion of results addresses the second research question about the patterns that emerged between responsiveness, inquiry instruction, and PCK during Annie's teaching responses. The theme of teacher beliefs emerged from the data. Annie showed discrepancies between her stated beliefs and her demonstrated beliefs. These discrepancies were significant because she stated her belief that higher levels of inquiry instruction produced higher levels of student understanding but often demonstrated a lesson-completion mindset. Although Annie frequently adapted instruction toward more student-focused inquiry strategies, she was disappointed when she could not complete lessons as planned.

Additionally, several times, Annie indicated that she shifted her lessons away from inquiry, but she simply moved away from conducting investigations toward another inquiry strategy based on student needs. Annie equated conducting investigations with inquiry, and she did not place as much value on the remaining components of the inquiry cycle. For example, she was disappointed when her class did not complete the solutions lab, but she supported them in designing a procedure. Annie stated that she wanted them to learn that skill but was very frustrated by not completing the lab. Her statements and attitude seemed to indicate a misunderstanding of the purpose of scientific practices in the inquiry cycle. It is possible that this way of thinking resulted from an overemphasis on the "hands-on" portion of inquiry during methods classes in her teacher preparation program.

Teacher knowledge was a second theme that resulted from the inductive analysis of the data. Specifically, two closely tied subthemes of competence and self-efficacy emerged. Annie had the highest levels of PCK for Big Idea A and was the most responsive and student-focused in her instruction. Annie had much lower levels of PCK for the solutions unit. She stated that she did not remember learning much about solutions as a student, so she was not confident in deciding what and how to teach that unit. According to Allen et al. [7], a teacher needs a well-developed knowledge base and connections to the real world to easily make necessary instructional moves. Annie's lower content competence and lack of self-efficacy hindered her ability to adapt instruction for Big Idea F. She did not adapt her instruction for Big Idea E; however, she began the lesson using a very student-focused inquiry approach with high levels of student engagement and understanding. For Big Idea B, Annie had relatively high levels of PCK for the concept. Still, the lesson was based solely on the mathematical calculations of stoichiometry and loosely connected to the conceptual understanding. She adjusted by providing the "mole map" as a scaffold, and the students were more engaged and had somewhat better understanding. However, she implemented the lesson using direct instruction methods, which were not on the continuum of inquiry instruction.

Annie did not utilize any inquiry strategies for mathematics lessons except for the introduction to Big Idea E. She incorporated Kool-Aid engagement and used questioning strategies to guide students to a conceptual understanding of concentration calculations. However, for the other formulas, she chose direct instruction, used a modeling strategy, and indicated that this was the only way she could think of to teach them. She also indicated her lack of self-efficacy and demonstrated a lack of knowledge of inquiry techniques during mathematics-focused lessons. Her deficiency in the ability to use inquiry instruction for mathematics topics and her subsequent inability to make mathematical connections to all but one science topic suggest that there may be a gap in teacher preparation for physical science teaching involving mathematical inquiry instruction.

7. Conclusions

This study provided an examination of nuance within the relationships between instructional practices and teacher knowledge. Positioning instruction on the inquiry spectrum is determined by students' needs for teacher support, and a higher level of inquiry is not always best for students [26,27]. Annie's responsiveness to students moved her instruction along the spectrum toward higher or lower levels of inquiry, sometimes deviating from her initial planning. For big ideas, where Annie scored higher on PCK, she responded to students' thinking, understanding, and questioning and positioned her instruction on the inquiry spectrum accordingly. For big ideas, where she scored lower on PCK, her ability to recognize student needs and respond with proper support and placement on the spectrum tended to be limited. Therefore, the findings support the previous research that inquiry and responsiveness are not mutually exclusive but work hand-in-hand to produce appropriate instructional practices [15]. Further, data also suggest that the intersection of PCK with inquiry and responsiveness can indicate the degree of their interaction. Thus, PCK might be an essential link to the inclusion of responsiveness in inquiry instruction and understanding of effective practices. Incorporating responsiveness within inquiry instruction with high levels of PCK holds promise for preparing teachers who can design and facilitate student-centered instruction with appropriate levels of teacher support. However, without explicitly teaching responsive practices and emphasizing all components of the inquiry cycle, science teacher educators risk instilling incomplete ideas about inquiry and neglecting the needs of individual students.

While there is a broad literature base examining the characteristics of inquiry instruction and responsive teaching, less scholarly attention has been paid to the degree of interaction between the two or the importance of PCK during the interaction [5,15,32]. More research is needed to examine the degree to which responsive practices are taught relative to inquiry methods in teacher preparation programs. Science teacher educators should examine responsive practices embedded within inquiry instruction while exploring preservice teachers' relative knowledge and skills. Additionally, science teacher educators should scrutinize the emphasis on individual inquiry strategies, such as carrying out investigations, within the context of methods classes. They should explore preservice teacher beliefs related to the importance of each phase of the inquiry cycle and how these beliefs impact instruction. Finally, an examination of mathematical knowledge and skills for preservice physical science teachers should be conducted. Science inquiry skills are stressed in teacher education; however, exploratory mathematics pedagogy may not be included in science teacher training. Studies in this area are needed to better understand the level of preservice physical science teacher mathematics PCK, the degree to which their mathematics and science PCK are connected, and their impact on inquiry instruction and responsive teaching.

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