THE ROLE OF PRESERVICE ELEMENTARY TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENCE TEACHING IN LEARNING TO ENGAGE IN CURRICULAR PLANNING

Abstract: Teachers often engage in curricular planning by critiquing and adapting existing curriculum materials in order to contextualize the resources and compensate for their deficiencies. Designing instruction for students is shaped by teachers’ ability to apply a variety of personal resources, including their pedagogical content knowledge (PCK) for science teaching. This knowledge domain is a teacher’s understanding of how to teach specific subject matter and is influenced by the transformation of pedagogical knowledge, subject matter knowledge, and knowledge of context. However, developing this knowledge and applying it in the analysis of science lesson plans is no easy task. This study investigated a criterion-based approach to analysis as one way to help preservice elementary teachers develop their PCK for science teaching and use this knowledge to plan instruction for students. Results show that the preservice teachers demonstrated a range of alternative understandings related to their knowledge of science assessment, science curriculum materials, and instructional strategies for teaching science. These alternative ideas were influenced, in part, by weaknesses in their pedagogical knowledge about learners and learning and their subject matter knowledge—specifically, their understanding of scientific inquiry. Despite these weaknesses in their teacher knowledge, the preservice teachers’ PCK for science teaching improved over time when they had the opportunity to practice applying the criteria using different lesson plans. Insights into PCK for science teaching and implications for science teacher education are discussed.

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THE ROLE OF PRESERVICE ELEMENTARY TEACHERS’ PEDAGOGICAL CONTENT KNOWLEDGE FOR SCIENCE TEACHING IN LEARNING TO ENGAGE IN CURRICULAR PLANNING

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Introduction

A growing body of research has investigated the ways in which teachers use curriculum materials to design and enact instruction (Bullough, 1992; Collopy, 2003, Drake & Sherin, 2009; Grossman & Thompson, 2004; Remillard, 1999; Schneider & Krajcik, 2002; Valencia, Place, Martin, & Grossman, 2006). This research has shown that effective teachers hold an analytical stance toward curriculum materials, critiquing and adapting them to achieve productive instructional ends. Critiquing materials here refers to evaluating a set of written materials by identifying its strengths and weaknesses (Davis, 2006; Drake & Sherin, 2009; Schwarz et al., 2008), and adapting materials refers to making changes to lesson plans to promote opportunities for student learning (Davis, 2006; Drake & Sherin, 2009). We use the term ‘analysis’ to refer simultaneously to both practices (Beyer, in preparation).

Teachers critique and adapt curriculum materials for two primary reasons. First, school districts routinely adopt and mandate the use of published curricular programs (Ball & Cohen, 1996; Ball & Feiman-Nemser, 1988; Remillard & Bryans, 2004). These materials equip teachers with much needed resources but vary in quality. For example, recent reviews of science curriculum materials show that many existing curricular programs are inconsistent with reform-based standards and practices (Beyer, Delgado, Davis, & Krajcik, in press; Hubisz, 2003; Kesidou & Roseman, 2002; Ochsendorf, Lynch, Pyke, O’Donnell, & Faubert, 2004; Stern & Roseman, 2004). The programs fail to establish a sense of purpose, attend to students’ alternative ideas, provide relevant phenomena and representations to illuminate abstract concepts, and scaffold students in making sense of key ideas. Poor quality materials do not adequately support students in achieving important content and inquiry learning goals and thus need to be critiqued and adapted in order to overcome these limitations.

Second, curriculum developers typically design curriculum materials for a wide audience and general context. Thus, teachers need to use their curriculum materials in flexibly adaptive ways in order to meet their specific contextual needs and anchor their students’ learning in productive ways (Barab & Luehmann, 2003; Brown, 2009; Enyedy & Goldberg, 2004; Pintó, 2004; Squire, MaKinster, Barnett, Luehmann, & Barab, 2003). Russell (1997) appropriately explained:

No matter how well curriculum materials are tested, no matter how many times they are revised, each school brings its own mix of resources and barriers, each classroom brings its own set of needs, styles, experiences, and interests on the part of both teacher and students, and each day in the classroom brings its own set of issues, catastrophes, and opportunities. (p. 251)
Thus, in creating learning experiences for students, teachers necessarily make local adaptations to curriculum materials given their own understandings and goals, particular students’ needs and strengths, and classroom circumstances.

Even though critiquing and adapting curriculum materials are essential aspects of teaching practice, novice teachers encounter difficulties with these tasks (Davis, 2006; Grossman & Thompson, 2004; Nicol & CRESPO, 2006; Schwarz et al., 2008). Teachers who do not know how to analyze curriculum materials in productive ways may fail to recognize the strengths and weaknesses in materials. Consequently, they may make counterproductive changes or may fail to make much needed modifications to lessons. Therefore, new teachers need support in learning how to critique and adapt curriculum materials. In this study we examine how preservice elementary teachers engage in these authentic teaching tasks as they are provided with support in their science methods course.

**Theoretical Framework**

**Teacher-Curriculum Materials Participatory Relationship**

This study is grounded in the theoretical perspective that teachers and curriculum materials participate together in a dynamic, collaborative relationship (Brown, 2009; Remillard, 2005). In contrast to other perspectives that view teachers as mere conduits of curriculum materials (e.g., Welch, 1979), this perspective views teachers as active agents who work together with curriculum materials to develop the planned curriculum and construct the enacted curriculum.

Curriculum materials play an active role in mediating this participatory relationship by enabling and constraining teachers’ curricular decision-making (Brown, 2009; Remillard, 2005). Shaped by historical, social, and cultural values, curriculum materials contain particular ideas that specify what science concepts are important to teach and what pedagogical methods are most effective. These material resources influence what teachers learn from curriculum materials and how they use them in practice (Cohen & Ball, 1999). For example, curriculum materials describing innovative pedagogical approaches may promote changes in teachers’ knowledge about how to teach the subject matter and ultimately result in changes in their practice.

Teachers also play an active role in the participatory relationship. As teachers read and interpret written materials, they draw upon their experiences, beliefs, knowledge, and instructional goals (Brown, 2009; Remillard, 2005). These personal resources help teachers bring meaning to the materials and ultimately shape how they enact the materials in practice (Cohen & Ball, 1999). For example, teachers may modify their materials to be responsive to their instructional goals and students’ needs. Thus, not only do curriculum materials shape teachers’ ideas and practices but teachers simultaneously shape curriculum materials as they use and adapt the materials in ways that address their own unique characteristics, needs, and goals.

**Pedagogical Content Knowledge for Science Teaching**

Teachers’ interactions with curriculum materials are mediated by their knowledge and beliefs about the subject matter, teaching, and learning (Brown, 2009; Collopy, 2003; Enyedy & Goldberg, 2004; Kauffman, 2002; Pintó, 2004; Remillard, 1999; Squire et al., 2003). These personal resources shape what teachers understand from reading the curriculum materials and
how they enact the materials with students. One personal resource of particular interest in this study is teacher’s pedagogical content knowledge (PCK). PCK is the knowledge that teachers use to help their students develop a deep understanding of specific subject matter (Shulman, 1986). This unique subject-specific body of knowledge results from an interaction among their general pedagogical knowledge, knowledge of context, and subject matter knowledge. (Grossman, 1990). This personal resource mediates teachers’ interactions with curriculum materials as they engage in curricular planning and thus impacts opportunities for student learning as well as opportunities teachers have to learn with and from the materials themselves.

PCK entails several knowledge components that work together to help teachers represent specific subject matter in a way that makes it comprehensible to students. Magnusson, Krajcik, and Borko (1999) created a model that specifies five different components of PCK for science teaching (see Figure 1). This model has formed the theoretical basis for much research on PCK for science teaching (see Abell, 2007 for her use of the model in organizing the research on science teacher knowledge). Magnusson and colleagues (1999) identified five components of the model, which they defined as: (a) orientations toward science teaching, which include an understanding of the purposes for and general approaches to teaching science; (b) knowledge of students’ understanding of science, which includes an understanding of the prerequisite knowledge that students need and the difficulties that students typically face when learning scientific subject matter; (c) knowledge of science curricula; (d) knowledge of science instructional strategies; and (e) knowledge of science assessment. The latter three dimensions are particularly relevant to this study and are elaborated in detail below.

![Figure 1. Model of pedagogical content knowledge for science teaching (modified from Magnusson, Krajcik, and Borko, 1999 and Abell, 2007).](image-url)
Knowledge of science curricula. Knowledge of science curricula is one component of pedagogical content knowledge for science teaching. Magnusson and colleagues (1999) identified two main dimensions of this component: knowledge of science goals and specific science curricula. Knowledge of science goals and objectives includes understanding what the key learning goals are for a particular topic as well as how these goals connect across different topics during the school year. Teachers determine these short-term and year-long goals by taking into consideration students’ prior knowledge and alternative ideas, the big ideas that are fundamental to the discipline, and the learning goals mandated by district, state, and national standards. The other dimension, knowledge of specific science curricula, includes an understanding of the specific curricular programs within science that are available for teaching particular topics. This includes knowledge of the general learning goals and activities within these programs. By knowing what programs and materials are available, teachers are able to make informed decisions about what resources to use with students.

Knowledge of science instructional strategies. Pedagogical content knowledge for science teaching also includes a repertoire of instructional strategies for teaching science. Knowledge of science instructional strategies includes two components: an understanding of science-specific strategies for teaching science, in general, and for teaching science topics, specifically (Magnusson et al., 1999). This understanding includes not only knowing about these instructional strategies but also how to use them and for what purposes. Science-specific strategies for any topic include such examples as the learning cycle, conceptual change model, guided inquiry, debate, and discovery. On the other hand, strategies for specific science topics include use of instructional representations (e.g., examples, models, analogies) and activities (e.g., problems, demonstrations, simulations, investigations, experiments). These particular strategies can help teachers represent or clarify science-specific topics for students.

Knowledge of assessment in science. One final component of pedagogical content knowledge for science teaching is knowledge of science assessment. Magnusson and colleagues (1999) defined this component as the knowledge that teachers have about what outcomes to assess in science and how to assess those outcomes. Important dimensions of science learning to assess include students’ understanding of key science concepts as well as their understanding and abilities necessary to engage in scientific inquiry. Teachers know what counts as evidence of what students have learned and align their assessments with learning goals. Additionally, teachers are familiar with different methods for assessing student learning and when they are appropriate to use. Examples of different kinds of assessments include observations, dialogue, tests, quizzes, performance-based assessments, portfolios, journal entries, lab reports, drawings, and other student artifacts. Knowing what methods to use for assessment helps teachers uncover their students’ understanding of science and know how to further build upon their students’ ideas to help them learn the subject matter.

Struggles Novice Teachers Face in Critiquing and Adapting Curriculum Materials

Teachers’ PCK for science teaching plays an important role in shaping how teachers interact with their curriculum materials (Brown, 2009; Remillard, 2005). Teachers use this knowledge to make informed decisions about how to critique and adapt lesson plans in order to provide powerful learning opportunities for students. However, many novice teachers are just beginning to develop their PCK for science teaching (Abell & Roth, 1992; Lederman, Gess-
Newsome, & Latz, 1994; van Driel, Verloop, & de Vos, 1998; for a review, see Davis, Petish, & Smithey, 2006) and thus encounter challenges in learning how to plan with curriculum materials in productive ways. For example, some preservice and beginning teachers follow their curriculum materials as written because they do not feel comfortable making changes to them (Ball & Feiman-Nemser, 1988; Grossman & Thompson, 2004). Other new teachers critique and adapt their materials, but their analysis ideas are often limited in scope, largely focused on the practical and affective aspects of teaching (Lloyd & Behm, 2005; Nicol & Crespo, 2006; Schwarz et al., 2008). Still other preservice and beginning teachers struggle with addressing the weaknesses they find in the materials, making superficial changes that do not address significant weaknesses or unproductive changes that distort the point of the materials (Ball & Feiman-Nemser, 1988; Grossman & Thompson, 2004; Nicol & Crespo, 2006).

These challenges highlight the need to support novice teachers in developing their PCK for science teaching and their ability to act upon this knowledge as they engage in curricular planning. However, relatively few studies have examined the ways in which beginning teachers apply their knowledge in the analysis of curriculum materials and how teacher educators can support them in doing so (Lloyd & Behm, 2005; Nicol & Crespo, 2006). More specifically, preservice elementary teachers’ critique and adaptation of science curriculum materials has been largely unexplored in the literature (Davis, 2006; Schwarz et al., 2008).

**Purpose of the Study**

This study addresses these gaps by investigating how well 24 preservice elementary teachers understand and apply a set of well-specified, standards-based criteria representing ideas about effective science teaching emphasized in their science methods course. By scaffolding the preservice teachers’ use of these criteria, we aimed to develop their PCK for science teaching, and in turn, their ability to analyze science curriculum materials in planning for instruction—specifically, their ability to recognize the strengths and weaknesses of materials and make beneficial adaptations.

The research questions guiding this study include: *When introduced to reform-based criteria and asked to apply them in their analyses, what are preservice elementary teachers’ understandings of the criteria and how do they apply them in their analyses of science lesson plans? How do their understandings change when they repeatedly apply the same criterion across multiple lesson plans?*

While the preservice teachers showed some strengths in their understandings of the criteria, much of our analysis here focuses on their alternative ideas—the places where we see specific weaknesses in their PCK for science teaching. We articulate these alternative ideas because we see these as having the most direct implications for improving teacher education.

**Research Methods**

**Research Context: The Methods Course**

This research study focused on one elementary science methods course at a large Midwestern university in the United States. This course took place during the third semester of an undergraduate teacher preparation program. This program consisted of two years (four semesters, each four months long). It included three semesters of university coursework and field observation and teaching in elementary school classrooms and a final semester of full-time student teaching. Preservice teachers typically entered the program during their third year of
college. The program was aligned with recommendations outlined by teacher education reform calls and standards documents (e.g., AAAS, 1993; NCTM, 1991; NCSS, 1994; NRC, 1996).

The elementary science methods course itself met for three hours each week during the fall semester of their final year of college. The first author taught the participants in this study. The course was organized around three overarching conceptual themes (Davis & Smithey, in press). The course helped preservice teachers develop their understanding of inquiry-oriented science teaching, attend to students’ ideas about science in their practice, and critique and adapt science curriculum materials. All three themes played an important role in this research study, with the third theme serving as the main focus in this investigation.

**Research Participants**

The participants in this study included the preservice elementary teachers from one section of the science methods course who gave their consent to have us analyze their coursework for research purposes (24 of 28 students). We informed the preservice teachers that they could withdraw their consent for participation at any time during the study and that we would maintain confidentiality using pseudonyms for all participants. The preservice elementary teachers recruited for this study were representative of the population of elementary teachers in the United States. In other words, they were primarily white and female (NCES, 2007). Most were also traditional fourth-year college students in their final year of study. With regard to their teaching concentrations, only one preservice teacher had a science concentration. The other preservice teachers had teaching concentrations in other subject areas, including language arts (12/24), mathematics (6/24), and social studies (6/24). Most of the preservice teachers (20/24) hoped to obtain a teaching job when they completed the program.

**Instructional Context—Learning about Reform-Based Criteria**

To help preservice teachers learn how to use curriculum materials in productive ways in their teaching practice, we promoted a criterion-based approach to analysis. Specifically, we introduced the preservice teachers to a set of well-specified, standards-based criteria. These criteria were based on the American Association for the Advancement of Science (AAAS) Project 2061 Instructional Analysis Criteria (Kesidou & Roseman, 2002; Stern & Roseman, 2004). (The Project 2061 curriculum-materials analysis procedure is based on existing research on student learning and is currently used at the national level to analyze science curriculum materials.) By scaffolding the preservice teachers’ use of these criteria, we aimed to develop the preservice teachers’ PCK for science teaching—as foregrounded in the criteria. In turn, we hoped to develop their ability to apply this knowledge in the analysis of science curriculum materials.

Other science methods courses have used the AAAS Project 2061 Instructional Analysis Criteria as a tool to scaffold preservice teachers’ curriculum materials analysis (Schwarz et al., 2008). As written, this framework includes several criteria organized into seven categories representing fundamental aspects of instruction, and each criterion includes several indicators and a scoring rubric for judging how well the curriculum materials meet each criterion (Kesidou & Roseman, 2002; Stern & Roseman, 2004). In the science methods course, we focused on six of the seven categories from the Project 2061 analysis framework and added one of our own categories—attending to learning goals. Additionally, we modified this framework to focus preservice teachers’ analyses at a larger grain size, redefining the levels of analysis. Specifically, what Project 2061 called ‘categories,’ we described as ‘criteria,’ and what Project 2061 called
‘criteria,’’ we described as ‘indicators’ for meeting each criterion. We did not include any scoring rubrics.

We based these modifications on a variety of reasons. First, the Project 2061 criteria are intended for use in analyzing textbooks, not individual lesson plans. Second, extensive training is required before individuals can effectively use this analysis framework—an opportunity not afforded by the time constraints of a one-semester course with other demands. Third, the preservice teachers were not likely to view the tasks of critiquing and adapting curriculum materials as authentic if asked to use the Project 2601 criteria as-written since classroom teachers do not use scoring rubrics as part of their daily work as teachers (Schwarz et al., 2008). Finally, focusing at a larger grain size was hypothesized to provide a more accessible entry point for learning about curriculum materials analysis, especially for individuals learning about a criterion-based approach to analysis for the first time.

The reform-based criteria used in this study addressed topics commonly taught in science methods courses (Davis, 2006; NRC, 1996; Schwarz et al., 2008; Smith, 2000). They represented complex ideas related to effective science teaching that were likely to need more unpacking and elaboration than other analysis criteria representing less complex ideas. The seven criteria included (1) attending to learning goals, (2) establishing a purpose, (3) eliciting students’ initial ideas and predictions, (4) providing experiences with phenomena, (5) promoting students’ sense-making, (6) assessing student learning, and (7) making science accessible for all students. Table 1 lists the seven analysis criteria along with a brief description of each criterion.

Table 1: Overview of Reform-Based Criteria Used in the Science Methods Course

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Description</th>
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<tbody>
<tr>
<td>1 Attending to learning goals</td>
<td>Considers whether learning goals address both science content and inquiry and are aligned with the activities and assessment.</td>
</tr>
<tr>
<td>2 Establishing a purpose</td>
<td>Considers whether the materials explicitly present a contextualized and meaningful driving question or problem.</td>
</tr>
<tr>
<td>3 Eliciting students’ initial ideas and predictions</td>
<td>Considers whether the materials provide teachers with questions or tasks for identifying and probing beneath students’ responses.</td>
</tr>
<tr>
<td>4 Providing experiences with phenomena</td>
<td>Considers whether the materials provide multiple and varied experiences with phenomena and opportunities to record data.</td>
</tr>
<tr>
<td>5 Promoting students’ sense making</td>
<td>Considers whether the materials provide students with opportunities to explore, explain, and revise their ideas.</td>
</tr>
<tr>
<td>6 Assessing student learning</td>
<td>Considers whether assessments focus on understanding of key ideas and provide opportunities for each student to express ideas.</td>
</tr>
<tr>
<td>7 Making science accessible for all students</td>
<td>Considers whether the materials create a welcoming classroom community that enables all students to experience success and that provides all students with a feeling of belonging.</td>
</tr>
</tbody>
</table>
One class session was devoted to learning about each criterion. Each class session engaged the preservice teachers in a variety of in-class activities and course readings to develop their understanding of each criterion. To practice applying the new criteria in their analysis of science lesson plans, the preservice teachers completed three lesson plan analysis assignments during the course. The preservice teachers also completed two reflective teaching assignments, which had them use criteria to analyze a lesson plan from their cooperating teacher and teach the revised lesson plan to students in their field placements. The preservice teachers also completed a variety of other assignments and were expected to attend and participate in all class sessions.

**Connections Between Pedagogical Content Knowledge for Science Teaching and Reform-Based Criteria**

Understanding the pedagogical ideas underlying the reform-based criteria used in the science methods course required that the preservice teachers develop particular aspects of their PCK for science teaching. The ideas foregrounded in the reform-based criteria overlapped in particular ways with the different components of this knowledge domain. In articulating these connections, we found that the understanding required for successfully applying some of the criteria directly mapped onto the knowledge components of PCK whereas the knowledge underlying successful application of other criteria required that we broaden the definition of some of the knowledge components initially described by Magnusson and colleagues (1999). The connections between the criteria and the components of PCK for science teaching are highlighted in Figure 2 and described in detail below.

![Figure 2. Connections between PCK for science teaching and reform-based criteria used in the science methods course.](image-url)
Criterion 6—‘assessing student learning’—was intended to foster preservice teachers’ knowledge of science assessment, including their understanding of assessment outcomes and methods. In applying criterion 6, teachers must understand the different dimensions of student learning that are important to assess, which include not only students’ science content knowledge but also their inquiry abilities and understandings. Additionally, teachers must have knowledge of different methods for assessment. Magnusson and colleagues (1999) defined this dimension in terms of understanding what the different methods for assessing student learning are (e.g., written tests, journal entries, portfolios) and when they are appropriate to use. Being able to apply criterion 6 includes this type of knowledge with additional specificity to its description. As teachers decide which methods are appropriate, they must consider whether the assessment method enables them to assess each student with regard to their learning goals and whether it enables students to apply their ideas to a new task or situation.

Criteria 2—‘establishing a purpose,’ 3—‘eliciting students’ initial ideas and predictions,’ 4—‘providing experiences with phenomena,’ 5—promoting students’ sensemaking,’ and 7—‘making science accessible to all students’—aimed to promote preservice teachers’ knowledge of science instructional strategies—specifically, their understanding of subject-specific strategies for any topic. Magnusson and colleagues (1999) defined these types of strategies as the general approaches to teaching science. Being able to apply these criteria requires this kind of knowledge with additional specificity. In applying the criteria, teachers must have knowledge of instructional strategies for supporting not only students’ understanding of science but also students’ scientific inquiry (Davis & Krajcik, 2005; Zembal-Saul & Dana; 2000). For example, teachers can help students learn about science topics by developing their knowledge of instructional strategies for establishing the purpose of a lesson (criterion 2) and eliciting students’ initial ideas about the content (criterion 3). On the other hand, teachers can help students engage in scientific inquiry by developing their knowledge of instructional strategies for supporting students in making predictions (criterion 3), engaging in scientific phenomena (criterion 4), collecting and analyzing data (criterion 4), and developing evidence-based explanations (criterion 5). Additionally, being able to apply the above criteria requires an understanding of not only the types of instructional strategies for enacting science instruction but also the ways in which teachers can successfully enact the strategies in practice. For example, for criterion 2, teachers must have strategies that not only make the purpose of the lesson explicit to students but that also help students see the lesson purpose as connected to previous lessons and meaningful to their own lives. Additionally, for criterion 3, teachers must have strategies that not only uncover students’ initial ideas and predictions but that also elicit explanations and provide opportunities for students to record and share these ideas.

Criterion 1—‘attending to learning goals’—aimed to develop preservice teachers’ knowledge of science curricula, and specifically, their understanding of science goals and objectives. Magnusson and colleagues (1999) simply described this dimension of curricular knowledge as having an understanding of national-, state-, or district-level curriculum frameworks, which specify the learning goals for students in the subjects that teachers are teaching. Being able to apply criterion 1 requires that teachers have this kind of knowledge so that they can determine if the learning goals within their lesson plans are grade-appropriate, aligned with standards documents, and address both content and inquiry standards. However, the application of criterion 1 also requires that teachers understand that learning goals need to be
PCK and curricular planning

aligned with lesson activities and assessments. This additional understanding broadens the initial description proposed for knowledge of science learning goals.

Finally, the set of criteria, taken as a whole, was intended to help preservice teachers develop their knowledge of science curricula. One dimension of this knowledge component described by Magnusson and colleagues (1999) included having familiarity with the science curricular programs available to teachers. We expanded this description to include knowledge not only about the types of curriculum materials but also about the fruitful ways in which they can be used in designing instruction for students. In this study, this specifically meant developing an understanding of productive analysis strategies, including knowing about a criterion-based approach to analysis and about the use of reform-based criteria, specifically. Therefore, being able to apply the set of criteria entailed an understanding of the ways in which teachers can use curriculum materials to promote student learning.

Data Sources

Lesson plan analysis assignments. The preservice teachers independently completed three lesson plan analysis assignments as homework during the science methods course. The preservice teachers analyzed a different inquiry-oriented science lesson plan for each assignment. The lesson plans represented a wide assortment of curriculum materials varying in content, grade level, and quality, providing preservice teachers with the opportunity to explore a range of resources. In the first assignment, the lesson plan focused on helping first and second graders learn about waterproofing as one of the properties of materials by having them test the ability of different materials to keep a cotton ball dry. The lesson plan for the second assignment involved the concept of seed dispersal, engaging second and third graders in investigating the seed dispersal methods of different types of seeds. In the third assignment, the lesson plan had fifth grade students learn about friction by testing how far a toy car can travel on a variety of different surfaces.

In each analysis, the preservice teachers applied three criteria that they had learned about in class in their analysis of the lesson plan. Each lesson plan intentionally contained both strengths and weaknesses with regard to each criterion. For each criterion, the preservice teachers had to identify aspects of the lesson plan that met or did not meet each indicator, provide rationales or examples from the materials to justify their ideas, and describe adaptations they would make to improve the lesson plan. Each assignment specified which criteria they would use in their analysis (see Table 2). The preservice teachers applied each reform-based criterion only once across the assignments, with the exception of one criterion (i.e., ‘eliciting students’ initial ideas and predictions’), which they applied in all three assignments. In their original discussion of scaffolds, Wood, Bruner, and Ross (1976) argued for the repetition of scaffolds in order to help learners apply what they had learned at one point in a task to later activity. Therefore, we repeated one criterion across the lesson plan analysis assignments to see if repetition made a difference in preservice teachers’ understanding and application of the criteria. See Appendix A for the instructions given to the preservice teachers for this assignment. We used this data source to describe how well preservice teachers applied reform-based criteria in their analysis of pre-selected, inquiry-oriented science lesson plans. Specifically, these assignments shed light on preservice teachers’ PCK for science teaching and their ability to apply this knowledge in the analysis of inquiry-oriented science lesson plans.
Table 2: List of Reform-Based Criteria for Each Lesson Plan Analysis Assignment

<table>
<thead>
<tr>
<th>Assignment</th>
<th>Reform-Based Criteria Targeted in Each Assignment</th>
</tr>
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</table>
| Lesson plan analysis assignment 1 | Eliciting students’ initial ideas and predictions  
Establishing a sense of purpose  
Attending to learning goals |
| Lesson plan analysis assignment 2 | Eliciting students’ initial ideas and predictions  
Providing experiences with phenomena  
Promoting student thinking |
| Lesson plan analysis assignment 3 | Eliciting students’ initial ideas and predictions  
Assessing students’ ideas  
Making science accessible for all students |

Reflective teaching assignments. The preservice teachers independently completed two reflective teaching assignments at the middle and end of the semester, providing them with the opportunity to teach two science lessons in their field placements. Each preservice teacher obtained their lesson plans from their cooperating teachers; these lesson plans were typically not inquiry-oriented. In these assignments the preservice teachers developed a revised lesson plan and enacted the lesson in their field placement. Like the lesson plan analysis assignments, the preservice teachers applied three criteria and their indicators by identifying aspects of the lesson plan that met or did not meet each indicator, justifying their ideas, and suggesting adaptations. However, unlike the other assignment, this task allowed them to choose their own criteria for their analysis. The preservice teachers had three weeks to complete each assignment. See Appendix B for the instructions given to the preservice teachers. We used this data source to describe how the preservice elementary teachers critique and adapt lesson plans that they are responsible for enacting in their field placements. Specifically, these assignments shed light on preservice teachers’ PCK for science teaching and their ability to apply this knowledge in the analysis of their own science lesson plans.

Data Coding and Analysis

We analyzed the preservice teachers’ lesson plan analysis assignments and reflective teaching assignments in order to determine whether they addressed the indicators of each reform-based criterion. We created a list of codes based on the reform-based criteria and sub-codes based on the indicators. The preservice teachers received the criteria and their indicators as part of the lesson plan analysis assignments. Table 3 includes this list of codes and sub-codes used in the analysis.
Table 3: Coding Scheme for the Application of the Reform-Based Criteria

<table>
<thead>
<tr>
<th>Code</th>
<th>Sub-Code</th>
<th>Example</th>
</tr>
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<tbody>
<tr>
<td>Attending to learning goals</td>
<td>Address content and inquiry</td>
<td>Learning goals address both science content and inquiry.</td>
</tr>
<tr>
<td></td>
<td>Connection to standards</td>
<td>Learning goals are grade-appropriate and aligned with standards documents.</td>
</tr>
<tr>
<td></td>
<td>Alignment with lesson</td>
<td>Learning goals are aligned with activities and assessments.</td>
</tr>
<tr>
<td>Establishing a purpose</td>
<td>Explicit purpose</td>
<td>Lesson prompts teacher to make lesson purpose explicit to students</td>
</tr>
<tr>
<td></td>
<td>Meaningful purpose</td>
<td>Purpose is likely to be meaningful to students and anchored in the lives of learners.</td>
</tr>
<tr>
<td></td>
<td>Connected purpose</td>
<td>Lesson helps teacher connect the purpose to what students have been learning about thus far in class.</td>
</tr>
<tr>
<td>Eliciting students’ initial ideas and predictions</td>
<td>Elicit ideas and predictions</td>
<td>Lesson enables teacher to elicit students’ ideas about the new content and predictions about phenomena.</td>
</tr>
<tr>
<td></td>
<td>Elicit explanations</td>
<td>Lesson asks students to give explanations for their ideas/predictions.</td>
</tr>
<tr>
<td></td>
<td>Record and share ideas</td>
<td>Lesson provides opportunities for students’ ideas to be recorded and shared with others in the class.</td>
</tr>
<tr>
<td>Providing experiences with phenomena</td>
<td>Multiple experiences</td>
<td>Lesson provides multiple experiences with phenomena—first- and second-hand experiences.</td>
</tr>
<tr>
<td></td>
<td>Data collection</td>
<td>Lesson engages students in recording their data or observations.</td>
</tr>
<tr>
<td></td>
<td>Data analysis</td>
<td>Lesson provides engages students in sharing their results and looking for patterns in the data.</td>
</tr>
<tr>
<td>Promoting students’ sense making</td>
<td>Evidence-based explanations</td>
<td>Lesson provides students with the opportunity to use evidence in support of a claim.</td>
</tr>
<tr>
<td></td>
<td>Discussion questions</td>
<td>Lesson provides teachers with questions to help students interpret their experiences with phenomena.</td>
</tr>
<tr>
<td></td>
<td>Revisiting of initial ideas</td>
<td>Lesson provides opportunities for students to revisit their initial ideas and predictions.</td>
</tr>
<tr>
<td>Assessing student learning</td>
<td>Assess content and inquiry</td>
<td>Lesson provides teachers with assessments that allow them to assess inquiry skills and science ideas.</td>
</tr>
<tr>
<td></td>
<td>Assess each student</td>
<td>Lesson provides teachers with assessments that allow each student to demonstrate understanding and skills.</td>
</tr>
<tr>
<td></td>
<td>Application of ideas</td>
<td>Lesson provides teachers with assessments that require students to apply their ideas to a new task/situation.</td>
</tr>
<tr>
<td>Making science accessible for all students</td>
<td>Attend to individuals</td>
<td>Lesson helps preservice teacher attend to the needs of individual students in his or her classroom.</td>
</tr>
<tr>
<td></td>
<td>Make explicit connections</td>
<td>Lesson enables students to make connections between scientific ideas and their personal experiences.</td>
</tr>
<tr>
<td></td>
<td>Make terms accessible</td>
<td>Lesson helps teachers make terminology accessible to all students.</td>
</tr>
</tbody>
</table>
For each indicator, we analyzed the preservice teachers’ response to determine whether they understood the intent of the indicator. We determined whether they understood its intent by analyzing their response for the presence of an accurate or inaccurate claim about whether the lesson plan met the indicator or not and the presence of correct or incorrect examples to support their claim (for a similar approach, see Schwarz et al., 2008). Each response that demonstrated an understanding of the indicator received one point and each response that demonstrated a lack of understanding received no points. Next, for each preservice teacher, we added up the points and assigned an overall score for each criterion based on how many indicators the preservice teachers accurately addressed in their analysis (see Table 4 for scoring rubric). Since each criterion had three indicators, the maximum score for any criterion was three. For each assignment we then averaged the scores across the preservice teachers for each criterion. We then conducted a repeated measures one-way analysis of variance (ANOVA) to determine if there was any statistical difference in the mean scores across criteria for each assignment, followed by post hoc pairwise comparisons. For these ANOVAs and all others in this study, we used the Geisser–Greenhouse conservative F-test as a correction to guard against violations of the sphericity assumption, and we used the Bonferroni inequality to control for Type I error rate during follow-up comparisons. These comparisons illuminated potential differences in the preservice teachers’ understanding of the reform-based criteria, and thus their PCK for science teaching, shedding light on whether they had difficulty understanding and applying some knowledge components more than others.

Table 4: Scoring Rubric for Assessing Preservice Teachers’ Understanding of Reform-Based Criteria

<table>
<thead>
<tr>
<th>Score</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Demonstrates strong understanding and use of criterion. (All 3 indicators met.)</td>
</tr>
<tr>
<td>2</td>
<td>Demonstrates adequate understanding and use of criterion. (Only 2 indicators met.)</td>
</tr>
<tr>
<td>1</td>
<td>Demonstrates weak or partial understanding and use of criterion. (Only 1 indicator met.)</td>
</tr>
<tr>
<td>0</td>
<td>Does not demonstrate understanding and use of criterion. (No indicators met.)</td>
</tr>
</tbody>
</table>

We conducted other statistical tests in order to describe changes in the mean scores over time. With regard to the lesson plan analysis assignments, we performed a repeated measures one-way ANOVA to determine if there was any statistical difference in the mean scores across assignments for criterion 3, which was the only criterion repeated across the assignments. We then conducted follow-up pairwise comparisons. Examining changes in scores across the semester shed light on how well the preservice teachers understood this aspect of PCK for science teaching and how their understanding changed across the semester as they practiced applying the criterion using different lesson plans.

Finally, for the lesson plan analysis assignments and reflective teaching assignments, we calculated the frequency and percentage of preservice teachers who demonstrated an understanding of each indicator in order to discern with which components of each criterion the preservice teachers tended to struggle. We then coded their analyses for evidence of alternative
understandings of the analysis criteria. We developed these codes from their analyses and identified patterns in these codes across the preservice teachers. This analysis shed light on the common alternative understandings they had with regard to their PCK for science teaching.

To enhance the validity of the study, we had a second independent rater code a subset of the data (10%) and calculated inter-rater agreement (Krefting, 1991). Specifically, we calculated relative observed percent agreement and Cohen’s kappa coefficient, which takes into consideration the agreement occurring by chance. Percent agreement between raters was 88 percent, and the value for kappa was 0.76, indicating substantial agreement. All disagreements were resolved through discussion. We also participated in discussions of our data analysis procedures and emerging findings with impartial colleagues at research meetings. This peer review process allowed us to obtain feedback on our coding schemes, emergent patterns, and interpretations, thereby bolstering the credibility of the assertions in this study (Lincoln & Guba, 1985).

Results

The first part of this section presents findings from the lesson plan analysis assignments and the second part presents findings from the reflective teaching assignments. Analyzing the preservice teachers’ analyses of science lesson plans provided insight into their ability to apply their newly developed PCK for science teaching when engaged in curricular planning. Thus, the following results are not simply a measure of what preservice teachers know but instead a measure of how preservice teachers apply what they know. In other words, the findings provide direct insight into preservice teachers’ knowledge-in-action and indirect insight into their actual knowledge for science teaching.

Understanding and Application of the Reform-Based Criteria

During the science methods course, the preservice teachers had the opportunity to learn about seven criteria that they could use to critique and adapt science lesson plans when designing instruction for students. The ideas underlying these criteria are grounded in the different components of PCK for science teaching. After learning about each reform-based criterion, the preservice teachers demonstrated their understanding of the criteria by applying them in their analysis of inquiry-oriented lesson plans selected by their course instructor, as part of their lesson plan analysis assignments. A repeated measures analysis revealed that the lesson plan analysis scores differed significantly among the seven reform-based criteria, $F(4.28, 98.54) = 8.61, p = .000$, with a moderate effect size (partial eta-squared = .27). With error rate corrections, follow up comparisons revealed that the scores for criteria 6 and 7 differed significantly from the rest of the criteria. Specifically, the preservice teachers demonstrated adequate understanding and application of five of the seven reform-based criteria but weak or partial understanding and application of two criteria—‘assessing student learning’ and ‘making science accessible to all students’ (see Table 5).
### Table 5: Mean Scores for Each Reform-Based Criterion in Lesson Plan Analysis Assignments

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Mean Score</th>
<th>SD</th>
<th>Depth of Understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Learning goals</td>
<td>1.67</td>
<td>0.92</td>
<td>Adequate</td>
</tr>
<tr>
<td>2-Purpose</td>
<td>1.96</td>
<td>0.86</td>
<td>Adequate</td>
</tr>
<tr>
<td>3-Eliciting ideas</td>
<td>1.92</td>
<td>0.83</td>
<td>Adequate</td>
</tr>
<tr>
<td>4-Experiencing phenomena</td>
<td>2.46</td>
<td>0.66</td>
<td>Adequate</td>
</tr>
<tr>
<td>5-Sense making</td>
<td>2.04</td>
<td>0.91</td>
<td>Adequate</td>
</tr>
<tr>
<td>6-Assessment</td>
<td>1.25</td>
<td>0.79</td>
<td>Weak or partial</td>
</tr>
<tr>
<td>7-Accessible Science</td>
<td>1.21</td>
<td>0.83</td>
<td>Weak or partial</td>
</tr>
</tbody>
</table>

\[a\] Score represents the number of indicators addressed by each preservice teacher for each criterion; maximum score = 3.0. \[b\] 0.00 - 0.49 = No understanding; 0.50 - 1.49 = Weak or partial understanding; 1.50 - 2.49 = Adequate understanding; 2.50 - 3.00 = Strong understanding

Within each criterion, the preservice teachers varied in their understanding and application of the individual indicators. Most of the preservice teachers accurately addressed about half of the indicators. However, the preservice teachers tended to struggle in their applications of the other indicators, especially with regard to indicators 1b, 6b, 7a, and 7c. Table 6 lists the percentage of preservice teachers who addressed each indicator within the lesson plan analysis assignments.

### Table 6: Percentage of Preservice Teachers Addressing Indicators within Lesson Plan Analysis Assignments

<table>
<thead>
<tr>
<th>Percentage of Preservice Teachers who Accurately Addressed Indicator</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most (67-100%)</td>
<td>1c—Aligning lesson to learning goals</td>
</tr>
<tr>
<td></td>
<td>2a—Making the purpose explicit to students</td>
</tr>
<tr>
<td></td>
<td>3a—Eliciting ideas/predictions at start of lesson</td>
</tr>
<tr>
<td></td>
<td>3b—Eliciting explanations for ideas/predictions</td>
</tr>
<tr>
<td></td>
<td>3c—Having students record/share ideas/predictions</td>
</tr>
<tr>
<td></td>
<td>4b—Having students record data</td>
</tr>
<tr>
<td></td>
<td>4c—Having students share/interpret their data</td>
</tr>
<tr>
<td></td>
<td>5a—Having students develop explanations</td>
</tr>
<tr>
<td></td>
<td>5c—Asking students to revisit their initial ideas</td>
</tr>
<tr>
<td></td>
<td>6c—Asking students to apply ideas to new tasks</td>
</tr>
<tr>
<td></td>
<td>7b—Connecting to personal experiences</td>
</tr>
<tr>
<td>Some (34-66%)</td>
<td>1a—including content and inquiry goals</td>
</tr>
<tr>
<td></td>
<td>2b—Making the purpose meaningful</td>
</tr>
<tr>
<td></td>
<td>2c—Connecting purpose to previous lessons</td>
</tr>
<tr>
<td></td>
<td>4a—Providing multiple experiences</td>
</tr>
<tr>
<td></td>
<td>5b—Asking guiding questions to discussion</td>
</tr>
<tr>
<td></td>
<td>6a—Assessing understanding and inquiry abilities</td>
</tr>
<tr>
<td>Few (0-33%)</td>
<td>1b—Connecting learning goals to standards</td>
</tr>
<tr>
<td></td>
<td>6b—Assessing each student’s ideas and abilities</td>
</tr>
<tr>
<td></td>
<td>7a—Attending to the individuals’ needs</td>
</tr>
<tr>
<td></td>
<td>7c—Making scientific terms accessible to all</td>
</tr>
</tbody>
</table>
After practicing applying the criteria in the lesson plan analysis assignments, the preservice teachers completed the reflective teaching assignments, where they analyzed their own lesson plans that they would be teaching in their field placements. A repeated measures analysis revealed that the mean scores for reflective teaching assignment 1 \[ F(1.90, 43.67) = 5.03, p = .012, \text{ with a small effect size (partial eta-squared } = .18) \] and assignment 2 \[ F(4.51, 103.79) = 10.01, p = .000, \text{ with a moderate effect size (partial eta-squared } = .30) \] differed significantly among the criteria across the preservice teachers. With error rate corrections, follow up comparisons revealed that the preservice teachers demonstrated a stronger understanding of criteria 1—‘attending to learning goals’ and ‘establishing a sense of purpose’—than the rest of the criteria (see Table 7). They demonstrated a weaker understanding of the rest of the criteria either because they misapplied the criteria in their analyses—illuminating their alternative understandings of the criteria—or simply because they disregarded the criteria as they revised their original lesson plans.

Table 7: Mean Scores for Each Reform-Based Criterion in Reflective Teaching Assignments

<table>
<thead>
<tr>
<th>Criterion</th>
<th>RT Assignment 1</th>
<th></th>
<th>RT Assignment 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Score</td>
<td>SD</td>
<td>Depth of</td>
<td>Mean Score</td>
</tr>
<tr>
<td></td>
<td>a</td>
<td></td>
<td>understanding b</td>
<td>a</td>
</tr>
<tr>
<td>1-Learning goals</td>
<td>2.10</td>
<td>0.75</td>
<td>Adequate</td>
<td>2.02</td>
</tr>
<tr>
<td>2-Purpose</td>
<td>2.00</td>
<td>0.51</td>
<td>Adequate</td>
<td>2.19</td>
</tr>
<tr>
<td>3-Eliciting ideas</td>
<td>1.58</td>
<td>0.69</td>
<td>Adequate</td>
<td>1.29</td>
</tr>
<tr>
<td>4-Phenomena</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.13</td>
</tr>
<tr>
<td>5-Sense making</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.08</td>
</tr>
<tr>
<td>6-Assessment</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.35</td>
</tr>
<tr>
<td>7-Accessibility</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>1.04</td>
</tr>
</tbody>
</table>

\(^a\) Score represents the number of indicators addressed by each preservice teacher for each criterion; maximum score = 3.0. \(^b\) 0.00 - 0.49 = No understanding; 0.50 - 1.49 = Weak or partial understanding; 1.50 - 2.49 = Adequate understanding; 2.50 – 3.00 = Strong understanding

Note: By the time the preservice teachers completed the first assignment, they had only learned about three criteria.

With regard to specific indicators of each criterion, the preservice teachers varied in how well they addressed them. Findings show that at least a few preservice teachers, if not more, were able to apply each indicator in their analysis of their own lesson plans. However, the majority of the preservice teachers accurately addressed only a few of the indicators across both analyses. These indicators pertained to criteria 1—‘attending to learning goals’—and 2—‘establishing a sense of purpose.’ Why might have this been the case? More than half of the preservice teachers did not even apply most of the reform-based criteria in their analysis, resulting in missed opportunities to improve their lesson plans (see Beyer, in preparation, for these results). Additionally, some of the preservice teachers who did apply the reform-based criteria did not address all of their indicators because they modified or omitted them in their analysis. Still other preservice teachers applied the reform-based criteria as-is but simply demonstrated alternative understandings of the indicators. Table 8 shows which indicators the preservice teachers tended to apply correctly and which indicators they frequently misapplied or did not attend to in the reflective teaching assignments.
Table 8: Percentage of Preservice Teachers Addressing Indicators within Reflective Teaching Assignments

<table>
<thead>
<tr>
<th>Percentage of Preservice Teachers who Accurately Addressed Indicator</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most (67-100%)</td>
<td>1b—Connecting learning goals to standards</td>
</tr>
<tr>
<td></td>
<td>1c—Aligning lesson to learning goals</td>
</tr>
<tr>
<td></td>
<td>2a—Making the purpose explicit to students</td>
</tr>
<tr>
<td></td>
<td>2c—Connecting purpose to previous lessons</td>
</tr>
<tr>
<td></td>
<td>3c—Having students record/share ideas/predictions</td>
</tr>
<tr>
<td>Some (34-66%)</td>
<td>1a—including content and inquiry goals</td>
</tr>
<tr>
<td></td>
<td>3b—Eliciting explanations for ideas/predictions</td>
</tr>
<tr>
<td></td>
<td>4b—Having students record data</td>
</tr>
<tr>
<td></td>
<td>4c—Having students share/interpret their data</td>
</tr>
<tr>
<td></td>
<td>5b—Asking guiding questions to discussion</td>
</tr>
<tr>
<td></td>
<td>5c—Asking students to revisit their initial ideas</td>
</tr>
<tr>
<td></td>
<td>6b—Assessing each student’s ideas and abilities</td>
</tr>
<tr>
<td></td>
<td>7c—Making scientific terms accessible to all</td>
</tr>
<tr>
<td>Few (0-33%)</td>
<td>2b—Making the purpose meaningful</td>
</tr>
<tr>
<td></td>
<td>3a—Eliciting ideas/predictions at start of lesson</td>
</tr>
<tr>
<td></td>
<td>4a—Providing multiple experiences</td>
</tr>
<tr>
<td></td>
<td>5a—Having students develop explanations</td>
</tr>
<tr>
<td></td>
<td>6a—Assessing understanding and inquiry abilities</td>
</tr>
<tr>
<td></td>
<td>6c—Asking students to apply ideas to new tasks</td>
</tr>
<tr>
<td></td>
<td>7a—Attending to the individuals’ needs</td>
</tr>
<tr>
<td></td>
<td>7b—Connecting to personal experiences</td>
</tr>
</tbody>
</table>

The preservice teachers demonstrated specific alternative understandings with regard to each of the criteria in both types of assignments. These alternative ideas are enumerated in Table 9. (For examples illustrating preservice teachers’ accurate and alternative understandings of the criteria within the lesson plan analysis assignments and reflective teaching assignments, see Appendices C and D, respectively.)
<table>
<thead>
<tr>
<th>Criterion</th>
<th>Alternative idea</th>
<th>Assignment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Attending to learning goals</td>
<td>1a: Analyzed lesson plan (not learning goals) for inquiry</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>1a: Had an alternative understanding of inquiry, in general</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>1b: Assumed learning goals are always connected to standards</td>
<td>X</td>
</tr>
<tr>
<td>2. Establishing purpose</td>
<td>2b: Analyzed purpose (not the lesson plan itself) to see if purpose was meaningful to students</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>2c: Analyzed purpose (not the lesson plan itself) to see if purpose was connected to other lessons</td>
<td>X</td>
</tr>
<tr>
<td>3. Eliciting students’ initial ideas &amp; predictions</td>
<td>3abc: Assumed students’ predictions was the same thing as students’ initials ideas about the new content</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>3b: Assumed that having students share their ideas out loud would elicit their explanations</td>
<td>X</td>
</tr>
<tr>
<td>4. Providing experiences with phenomena</td>
<td>4a: Interpreted providing multiple experiences with phenomena to mean engaging students in different aspects of the lesson plan</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>4a: Interpreted providing multiple experiences with phenomena to mean promote learning through different styles</td>
<td>X</td>
</tr>
<tr>
<td>5. Promoting sensemaking</td>
<td>5a: Equated having students develop a scientific explanation with having them share what they learned or having them state a claim but without evidence</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>5b: Did not know how to design discussion questions</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>5c: Did not have students revisit their initial ideas</td>
<td>X</td>
</tr>
<tr>
<td>6. Assessing student learning</td>
<td>6a: Assumed assessments are always connected to learning goals</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>6b: Did not individually assess student learning</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>6b: Thought it was only important to assess individual’s content ideas, not their inquiry abilities</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>6b: Assumed worksheets would allow them to assess individuals with regard to all of their learning goals</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>6c: Interpreted having students apply their ideas to a new task to mean having students apply what they have learned from a reading/experiment to complete a worksheet</td>
<td>X</td>
</tr>
<tr>
<td>7. Making science accessible to all students</td>
<td>7a: Looked for ways to help students, in general, rather than help individual students, specifically</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>7b: Did not help students see connections between science and their own experiences</td>
<td>X</td>
</tr>
<tr>
<td></td>
<td>7c: Assumed providing students with definitions made science accessible to all students</td>
<td>X</td>
</tr>
</tbody>
</table>
For criterion 1—‘attending to learning goals,’ the preservice teachers had to analyze the learning goals in lesson plans to determine if both content and inquiry learning goals were included. Though some preservice teachers were successful in this analysis, others struggled because they had an alternative understanding of scientific inquiry. Others did not successfully apply this indicator because they analyzed the lesson plan, not the learning goals themselves, for inquiry. Thus, they did not understand the difference between having explicitly stated learning goals that address inquiry and having a lesson plan that includes inquiry practices. These alternative understandings may result in missed opportunities for helping students develop their inquiry understandings and abilities. Additionally, in their analysis, the preservice teachers had to determine if the learning goals were aligned with standards. In attending to this indicator, some of the preservice teachers just assumed the learning goals would be automatically connected to standards, leading them not to check the standards documents for themselves. Making this assumption may result in missed opportunities for students to learn about particular science content and inquiry practices.

For criterion 2—‘establishing a sense of purpose,’ the preservice teachers had to determine if lesson plans helped students see the purpose of the lesson as meaningful to their own lives and connected to previous lessons. While some preservice teachers accurately analyzed the lesson purpose for these features, others did not. These preservice teachers analyzed how meaningful and connected the lesson purpose was rather than how well the lesson plan helped students see these features for themselves. They thought that just because the lesson purpose was anchored in the lives of learners and connected to previous lessons that students would automatically see it as such. Interpreting the indicator in this way may result in missed opportunities to help students see how lessons relate to their everyday lives and previous learning experiences.

For criterion 3—‘eliciting students’ initial ideas and predictions,’ the preservice teachers had to analyze lesson plans to determine if there were opportunities for students to make predictions. Unfortunately, most of them did not know what a prediction was, equating students’ predictions with their initial ideas about the new content. This alternative understanding may limit opportunities for students to develop their understandings of and abilities with making predictions. Additionally, within this criterion, the preservice teachers had to elicit students’ explanations for their initial ideas about the science content and their predictions. In interpreting this indicator, some of the preservice teachers assumed that having students share their ideas out loud would allow them to give explanations. The preservice teachers either assumed that sharing ideas in discussion was the same thing as providing explanations for ideas or that sharing ideas out loud would necessarily lead students to explain their ideas. Making either of these assumptions limits opportunities to find out the origin of students’ initial ideas and predictions.

For criterion 4—‘providing experiences with phenomena,’ the preservice teachers had to analyze lesson plans to see if students had the opportunity to experience the scientific phenomena in multiple ways, whether through first-hand or vicarious experiences or even through instructional representations. While some preservice teachers accurately applied this indicator, others did not. These preservice teachers thought that providing students with multiple experiences with phenomena meant either engaging students in different elements of the lesson plan (e.g., completing a worksheet, conducting the hands-on activity, participating in concluding discussion) or promoting learning through different learning styles (e.g., auditory, visual, kinesthetic). These examples show that some of the preservice teachers did not understand what counted as an experience with phenomena. Failing to understand this pedagogical idea may
result in missed opportunities for students to experience a range of phenomena, and in turn, help students see science ideas as having explanatory power.

For criterion 5—‘promoting sensemaking,’ the preservice teachers had to analyze the lesson plan for opportunities for students to construct evidence-based explanations. Many preservice teachers struggled with attending to this indicator because they possessed an alternative understanding of a scientific explanation. Some preservice teachers defined an explanation as any statement that provided reasons or details for something. Others conceptualized an explanation even more broadly, defining it as any response to a question where students have the opportunity to share their ideas. In this view, having students ‘tell,’ ‘describe,’ or ‘explain’ what they think were all viewed as synonymous terms. Both of these alternative understandings of a scientific explanation have one thing in common—a de-emphasis on the role of evidence. Failing to hold students accountable for providing evidence for their ideas may result in missed opportunities for students to learn how to support their ideas and make connections between scientific concepts and their explorations. In addition to this indicator, the preservice teachers also had to determine if the lesson plan provided fruitful questions for facilitating discussion and opportunities for students to revisit their initial ideas about the content at the end of the lesson. However, especially in analyzing their own lesson plans, the preservice teachers did not include these two features in their lesson plan, limiting their ability to guide students’ interpretation and reasoning.

For criterion 6—‘assessing student learning,’ the preservice teachers had to analyze lesson plans for ways to assess all of their learning goals. Some preservice teachers checked for alignment between the assessments and learning goals while others incorrectly assumed that the assessments would automatically be aligned. Possessing this alternative understanding may result in missed opportunities to assess some learning goals, limiting what they would be able to say about what students understand and are able to do. Additionally, the preservice teachers had to determine if the assessments would enable them to assess each student with regard to their learning goals. Many preservice teachers did not look for ways to individually assess student learning or thought it was sufficient to assess individual students with regard to their content learning goals but not their inquiry learning goals. Failing to assess each student’s inquiry abilities may limit opportunities to help students improve their understandings of and abilities necessary to do inquiry. Other preservice teachers incorrectly assumed that a science worksheet would always enable them to assess their students with regard to all of their learning goals. Assuming that teachers can rely exclusively on provided worksheets to assess all of their students’ content understandings and inquiry abilities may limit opportunities to assess what students have learned in their science investigations. Additionally, in applying this criterion, the preservice teachers had to look for opportunities for students to apply their ideas to a new task or situation. Many of them simply thought this meant having students apply what they had learned from a reading or experiment to complete a worksheet. Thus, these preservice teachers did not give students a new task or situation in which to apply their new knowledge. This alternative understanding may limit their ability to see if students can extend their ideas beyond the specific situation in which they are introduced.

For criterion 7—‘making science accessible to all students,’ the preservice teachers had to analyze lesson plan in terms of attending to the needs of individual students. Most of them interpreted this to mean looking for ways to help students, in general—for example, by modeling how to do an experiment or circulating while students work independently—rather than specific
students or groups of students. Focusing only on a class as a whole rather than on individual students may result in missed opportunities to attend to the needs of every student and thus to help all students experience success in learning about science. Additionally, the preservice teachers needed to help students make connections between the scientific ideas and their own social, cultural, and personal experiences. In analyzing their own lesson plans, the preservice teachers did not attend to this indicator in their analysis. Finally, in analyzing lesson plans to make terminology accessible to all students, the preservice teachers thought they simply needed to provide students with a list of definitions at the beginning of the lesson. Assuming students learn science merely by memorizing definitions may result in missed opportunities for students to make sense of science for themselves and thus to develop a deep understanding of scientific concepts.

**Summary**

The preservice teachers demonstrated a number of strengths and weaknesses in their understanding of the reform-based criteria in their analysis of their own lesson plans. Across both the lesson plan analysis assignments and the reflective teaching assignments, the preservice teachers demonstrated adequate understanding and application of two criteria—‘attending to learning goals’ and ‘establishing a sense of purpose.’ Despite these strengths, the preservice teachers tended to demonstrate weak or partial understanding of the rest of the reform-based criteria, especially ‘assessing student learning’ and ‘making science accessible to all students.’

**Understanding and Application of a Repeated Reform-Based Criterion**

The preservice teachers repeatedly applied one criterion across the lesson plan analysis assignments in order to determine if applying the same criterion using different lesson plans might improve their PCK for science teaching for that particular knowledge component. This criterion focused on developing an understanding of instructional strategies for ‘eliciting students’ initial ideas and predictions.’ A repeated measures analysis revealed that the assignment scores differed significantly across time for this criterion, $F(1.90, 43.63) = 34.61, p = .000$, with a large effect size (partial eta-squared = .60). Post hoc pairwise comparisons, corrected using Bonferroni adjustments, revealed a significant difference in mean scores for criterion 3 across all three assignments. The preservice teachers scored significantly lower on the second lesson plan analysis assignment, in comparison to the first assignment, but scored significantly higher on the third assignment, in comparison to the first two assignments (see Table 10 for mean scores). A qualitative description of their understanding of this criterion across time is presented below.

<table>
<thead>
<tr>
<th>Lesson Plan Analysis Assignment</th>
<th>Mean Score $^a$</th>
<th>SD</th>
<th>Depth of Understanding $^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.92</td>
<td>0.83</td>
<td>Adequate</td>
</tr>
<tr>
<td>2</td>
<td>0.54</td>
<td>1.02</td>
<td>Weak or partial</td>
</tr>
<tr>
<td>3</td>
<td>2.50</td>
<td>0.72</td>
<td>Strong</td>
</tr>
</tbody>
</table>

$^a$ Score represents the number of indicators addressed by each preservice teacher for each criterion; maximum score = 3.00. $^b$ 0.00 - 0.49 = No understanding; 0.50 - 1.49 = Weak or partial understanding; 1.50 – 2.49 = Adequate understanding; 2.50 – 3.00 = Strong understanding

Two-thirds of the preservice teachers correctly applied the indicators for ‘eliciting students’ initial ideas and predictions’ in the first lesson plan analysis assignment, demonstrating
adequate understanding and application of criterion 3 (see Appendix C for examples). The lesson plan in the second assignment contained different strengths and weaknesses from that of the first lesson plan with regard to this criterion. One difference was that the second lesson plan did not provide an opportunity for students to make predictions. However, only five preservice teachers identified this omission in the lesson plan, writing, for example:

I did notice the teacher doesn't have them predict how the seeds they are working with will travel. They are directed to draw them and record their names, but there isn't a time where they predict how it disperses based on their characteristics. I would change this part by having the students observe the seeds they are given, then make a prediction of how they travel either by wind, water, or animal (hitchhiker), and then have them explain why they chose that option. (Melanie, Lesson plan analysis assignment 2)

Aside from this handful of preservice teachers, the rest of the class did not recognize that the lesson plan failed to elicit students’ predictions because they had an alternative understanding of what a prediction was. These preservice teachers viewed students’ predictions about the phenomena as the same thing as their initial ideas about the new content. As a result, these individuals mistakenly asserted that the lesson plan elicited both students’ initial ideas and predictions. For example, Debbie incorrectly pointed to the opening discussion as the place where the teacher could elicit both students’ ideas and predictions. She wrote:

The two questions that the teacher asks about where new plants grow and why new plants do not grow under a parent plant allows the teacher to elicit further ideas about the new content, as well as having students make predictions during this discussion on the new content. (Debbie, Lesson plan analysis assignment 2)

This typical example shows that most of the preservice teachers were unable to distinguish between eliciting students’ initial ideas and their predictions. They did not understand that predictions deal specifically with students’ ideas about what they think the results from an experiment or investigation will be. As a result, the preservice teachers incorrectly applied all three indicators with regard to students’ predictions about the phenomena. Thus, the second assignment revealed that most of the preservice teachers had a weak understanding of criterion 3.

Like the other two lesson plans, the lesson plan for the third assignment also emphasized different strengths and weaknesses with regard to this criterion. It elicited students’ initial ideas about the new content and predictions about the phenomena at the beginning of the lesson. Most of the preservice teachers (21/24) identified these places in the lesson plan, as illustrated by Ashley’s analysis:

The teacher does elicit students' ideas about the new content (Friction). In the getting started section of the lesson plan the teacher writes the word ‘friction’ on the boards and asks students to share what they think the word might mean. After they come up with ideas the teacher tells them what friction is. She allows the students to feel the three different surfaces they will be using in their experiment and has them make predictions about on which surface the toy car will travel the longest distance and the shortest distance. This allows students to make predictions about the phenomena. (Ashley, Lesson plan analysis assignment 3)

The third lesson plan also asked students to give explanations for their predictions but not for their initial ideas. Three-quarters of the preservice teachers (18/24) successfully identified when
students had the opportunity to give explanations and when they did not. Michelle illustrated this understanding and modified the lesson plan to compensate for its weakness, writing:

At the beginning of the lesson the students are told to give explanations for their predictions about the phenomena, but are not asked for explanations about friction in general. The teacher should tell students to be prepared to explain 'why' they think friction is what they share with the class. Students can mention what leads them to believe friction exists, or can explain where they have seen friction working in their everyday lives. (Michelle, Lesson plan analysis assignment 3)

Finally, the third lesson plan asked students to share their initial ideas but not their predictions and to record their predictions but not their initial ideas. Again, most of the preservice teachers (20/24) pinpointed these strengths and weaknesses in the lesson plan and made a variety of adaptations to address these weaknesses, writing, for example:

The lesson does not allow for the students to record their ideas about the new content ‘friction’ but does allow for students (but not all) to share their ideas. The teacher is to ‘write the word ‘friction’ on the board and then ask students what they think this word means.’ I would make sure to include opportunities for students to not only share their ideas about the word friction but perhaps be able to record their ideas in their notebooks. The lesson does allow for students to record their predictions on their Notebook pages and explanations but it does not say for the students to share them with the class. I would like to add a short discussion after the students record their predictions to give them the opportunity to share their predictions with the rest of the class. (Debbie, Lesson plan analysis assignment 3)

Overall, by the third assignment, the majority of the preservice teachers correctly applied all three indicators, demonstrating strong understanding and application of criterion 3.

**Summary**

The preservice teachers demonstrated adequate understanding and application of criterion 3 in their initial analysis. However, their second analysis of a lesson plan, which highlighted different strengths and weaknesses from the first lesson plan that they analyzed, revealed that the preservice teachers did not have a complete understanding of this criterion. Specifically, they had an alternative understanding of what a prediction was. They viewed students’ predictions about the phenomena as the same thing as their initial ideas about the new content. Thus, they failed to recognize that the lesson plan did not enable students to make predictions. By the third analysis, the preservice teachers had demonstrated a strong understanding of criterion 3—the highest level of understanding attained among all of the criteria. Thus, their PCK for science teaching improved with repeated opportunities to apply their knowledge in analyzing science lesson plans.

**Discussion and Implications**

Curriculum materials play a fundamental role in shaping classroom instruction, helping teachers make thoughtful decisions about practice. Effective teachers use curriculum materials as a guide, critiquing and adapting them in order to compensate for their weaknesses and address specific student needs and circumstances (Barab & Luehmann, 2003; Brown, 2009). Even though analyzing curriculum materials is an essential aspect of teaching practice, preservice teachers encounter many difficulties in doing so (Davis, 2006; Schwarz et al., 2008). To support preservice elementary teachers in developing beginning levels of proficiency in critiquing and
adapting science curriculum materials, this study focused on the use of reform-based criteria. The participants in this study learned about these criteria through readings and in-class activities and applied the criteria in their analysis of inquiry-oriented lesson plans. They also analyzed some of their own lesson plans from their field placements using criteria of their own choosing. By scaffolding the preservice teachers’ use of reform-based criteria, we aimed to develop their understanding of the different dimensions of PCK for science teaching—as foregrounded in the criteria—and their ability to apply that knowledge in the analysis of science curriculum materials.

**Strengths in Preservice Teachers’ PCK for Science Teaching**

In developing their capacity for curricular planning, the preservice teachers demonstrated some strengths in their PCK for science teaching. The preservice teachers exhibited knowledge of science goals and objectives. They recognized that learning goals need to connect to standards and align with lesson activities and assessments. The preservice teachers likely understood how to attend to learning goals because they had had practice critiquing and adapting learning goals in a previous methods course. Thus, not surprisingly, preservice teachers may be more likely to understand particular aspects of PCK for science teaching if they have prior knowledge about these aspects.

The preservice teachers also demonstrated knowledge of instructional strategies for establishing a sense of purpose within a lesson. They recognized that the lesson purpose needs to be anchored in the lives of learners and connected to what students have been learning about in class. The preservice teachers might have easily developed an understanding of this aspect of PCK for science teaching because the intended meaning of ‘establishing a sense of purpose’ aligned well with their own goals for and understandings of science teaching. They recognized the importance of relating science to students’ everyday lives, helping them interpret the criterion in this way. In contrast, Schwarz and colleagues (2008) found that preservice teachers had difficulty accurately applying this criterion in their analyses because their own priorities for science teaching did not align well with the intended meaning of the criterion. Like other beginning teachers (Mellado, 1998; Meyer, Tabachnick, Hewson, Lemberger, & Park, 1999), these preservice teachers prioritized promoting general motivation and interest, leading them to interpret the criterion ‘establishing a sense of purpose’ in this way rather than in terms of making the lesson purpose meaningful and relevant to students. Thus, these findings show that preservice teachers may be more likely to develop their understanding of particular dimensions of PCK for science teaching if these dimensions are well aligned with their own goals for and understandings of science teaching.

**Weaknesses in Preservice Teachers’ PCK for Science Teaching**

Even though the preservice teachers demonstrated strengths in their understanding of some of the components of PCK for science teaching, they also exhibited a number of alternative ideas. The preservice teachers expressed undeveloped and naïve ideas dealing with some of the specific criteria as well as with the set of criteria as a whole, as detailed below.

First, the preservice teachers expressed limited knowledge about science assessment. Specifically, they had alternative ideas about what and how to assess—both components within Magnusson and colleagues’ model of PCK for science teaching. With regard to dimensions of science learning to assess, the preservice teachers tended to think about assessment exclusively in terms of students’ content understandings rather than also in terms of students’ inquiry
abilities and understandings. With regard to methods of assessment, some of the preservice teachers assumed that assessments are automatically aligned with learning goals and that science worksheets provided in curriculum materials always enable the teacher to assess all aspects of student learning—including both content understandings and inquiry abilities. Some of the preservice teachers also mistakenly thought that having students’ apply their newly developed knowledge means having them use what they had learned from an experiment or reading to complete a worksheet directly related to the in-class activity rather than to complete a new task. Additionally, the preservice teachers assumed that they could draw conclusions about individual student’s learning from assessments focused at the whole-class level. One explanation for these limited ideas about science assessment is that the preservice teachers may not have spent much time thinking about learners and learning. New teachers tend to focus on themselves as teachers, developing their knowledge and skills for teaching at the exclusion of thinking about how to assess and respond to learners (Fuller, 1969; Furlong & Maynard, 1995; LaBoskey, 1994).

Second, the preservice teachers expressed naive ideas related to their knowledge about science curricula—specifically, about the design of curriculum materials. For example, some of them assumed that learning goals are necessarily connected to standards and assessments are automatically aligned with learning goals. One explanation for these incorrect assumptions is that the preservice teachers may have taken the curriculum materials as a given. They might have assumed, like other beginning teachers, that experts developed the curriculum materials (Ben-Peretz, 1990; Bullough, 1992; Schwarz et al., 2008) or that the curriculum materials were of high quality because they were published (Ball & Feiman-Nemser, 1988; Ben-Peretz, 1990). Several studies have characterized teachers’ perspectives on curriculum materials, in general (Ben-Peretz, 1990; Bullough, 1992; Collopy, 2003; Kauffman, 2002; Remillard, 1999; Remillard & Bryans, 2004; Schwarz et al., 2008; Valencia et al., 2006), but have not explicitly examined teachers’ ideas and assumptions about specific features of curriculum materials. Therefore, this study extends existing research by describing some of the alternative ideas that preservice teachers may have about certain curricular features, including particular naïve ideas about the design of learning goals and assessments.

Third, the preservice teachers demonstrated limited knowledge about science instructional strategies—another important component of PCK for science teaching. Several explanations help account for this finding. These explanations relate to weaknesses in the preservice teachers’ pedagogical knowledge and subject matter knowledge—domains of teacher knowledge that influence the development of teachers’ PCK (Grossman, 1990; Magnusson et al., 1999).

Some of the preservice teachers had naïve ideas related to their pedagogical knowledge about learners, which may have contributed to their limited knowledge of science instructional strategies. Specifically, they had alternative ideas about what it means to make science accessible to all students, which limited their understanding of productive instructional strategies for helping students learn science. For example, many preservice teachers thought that one strategy for making science accessible included having the teacher provide students with terms and definitions at the beginning of a lesson without grounding them in students’ experiences. They also thought that the teacher can make science accessible to all students by simply having strategies to help students, in general—for example, by modeling how to do an experiment or circulating while students work independently—rather than attending to the needs of individual students or groups of students. They also did not think to help students make connections
between the scientific ideas and their personal, cultural, and social experiences. Other research studies have also shown that preservice teachers often do not consider individual students’ backgrounds, strengths, or needs when planning for science instruction (Davis, 2006; Schwarz et al., 2008; Southerland & Gess-Newsome, 1999). For example, Davis (2006) found that her preservice teachers applied an impressive repertoire of criteria when critiquing lesson plans but ignored other criteria, such as equity, altogether.

A second reason for the preservice teachers’ limited knowledge of science instructional strategies was their alternative ideas about student learning, another aspect of their pedagogical knowledge. Specifically, the preservice teachers assumed that students automatically make connections between ideas without support. For example, they thought that students are able to connect the lesson purpose to their own lives and to previous lessons without having these connections be made explicit to them. Several preservice teachers also thought that the connection between terms and definitions and students’ own learning experiences would be obvious to students. Additionally, they did not have students revisit their initial ideas about the new content at the end of the lesson because they assumed that students would revisit these ideas on their own as they made sense of their own science experiences. Preservice teachers often do not consider students and student learning very extensively or in very sophisticated ways (Southerland & Gess-Newsome, 1999; Zemba-Saul, Blumenfeld, & Krajcik, 2000). This study supports this idea by highlighting one naivety within preservice teachers’ understanding of student learning—that connections among ideas are always obvious to students—and providing examples of how this assumption may impact opportunities for student learning.

A final reason why the preservice teachers demonstrated a limited understanding about productive instructional strategies for learning science included limitations in their subject matter knowledge, specifically their understanding of different dimensions of scientific inquiry. For example, some of the preservice teachers equated students’ predictions about the phenomena with students’ initial ideas about the new content. They also had alternative ideas about what it means to provide students with multiple experiences with phenomena, which was defined as providing a range of relevant firsthand experiences with real-world phenomena, and if not practical, vicarious experiences and representations (Kesidou & Roseman, 2002; Stern & Roseman, 2004). Some interpreted this inquiry feature to mean having students experience different components of a lesson plan—for example, completing a worksheet, engaging in a hands-on activity, and participating in discussions. Others thought it meant having students experience different learning styles—auditory, visual, and kinesthetic. The preservice teachers also demonstrated a range of ideas with regard to having students develop scientific explanations, which the course, in line with the science education research literature (e.g., McNeill, Lizotte, Krajcik, & Marx, 2006), defined as supporting a claim with evidence. Some of them thought that having students share what they have learned at the end of class or having students share their ideas out loud elicited scientific explanations. Others thought that having students state a claim but without evidence counted as explanation construction. Other studies have similarly found that preservice teachers tend to have undeveloped or unrefined ideas about scientific inquiry (Haefner & Zembal-Saul, 2004; Smith & Anderson, 1999). The way in which teachers understand scientific inquiry directly impacts their knowledge of instructional strategies for promoting scientific inquiry and thus whether reform-based teaching is promoted or hindered in the science classroom. Unfortunately, little is known about teachers’ knowledge and beliefs about scientific inquiry (Davis et al., 2006). This study adds to what we know about these
teacher characteristics by highlighting particular alternative ideas that preservice elementary teachers may have about specific inquiry practices.

**Benefits of Providing Ongoing Support in the Development of Preservice Teachers’ PCK for Science Teaching**

This study also sheds light on some of the benefits of the design of the supports for helping preservice teachers develop their PCK for science teaching and apply their knowledge in their analysis of science lesson plans. Findings showed that the preservice teachers’ PCK for science teaching improved with repeated opportunities to apply their knowledge in analyzing science lesson plans. Specifically, the criterion ‘eliciting students’ initial ideas and predictions’ was repeated across the lesson plan analysis assignments. Applying the same criterion within different lesson plans enabled the preservice teachers to develop an improved understanding of the criterion over time, and by the posttest analysis, develop a stronger understanding of this criterion, in comparison to the other criteria.

These findings add to what we know about how to support preservice teachers in developing their PCK for science teaching and applying this knowledge in the critique and adaptation of science curriculum materials. Previous reports have found that having preservice teachers apply criteria only once within a scaffolded task resulted in mixed success in having the preservice teachers develop an understanding of the pedagogical ideas underlying the criteria (Schwarz et al., 2008) and limited long-term changes in these understandings (Beyer & Davis, in press). This study extends these findings by providing concrete evidence for the idea that preservice teachers are able to develop a more robust understanding of particular dimensions of PCK for science teaching when provided with multiple opportunities to practice applying that knowledge before the scaffolds are faded. This finding is consistent with other researchers who argue that the fading of scaffolds needs to be synchronized with the gradual development of learners’ understanding rather than abruptly removed before learners are ready to complete the task on their own (Collin, Brown & Newman, 1989; Pea, 2004). Thus, this study shows that preservice teachers may need opportunities to apply the same criteria in multiple contexts with scaffolds gradually faded as preservice teachers develop their PCK for science teaching and their capacity to apply this knowledge in productive ways to the task of analysis.

**Theoretical Implications for PCK for Science Teaching**

This study extends the field’s understanding of the different components of PCK for science teaching, as defined by Magnusson and colleagues (1999), by further articulating particular ideas to include in their model. With regard to knowledge of science curricula—science goals and objectives, we defined this knowledge component to include not only an understanding of national-, state-, or district-level curriculum frameworks but also an understanding that learning goals need to be aligned with lesson activities and assessments. With regard to knowledge of science curricula (i.e. in particular, knowledge of specific science curricula), we included the idea that teachers also need to have an understanding of the particular features of curriculum materials and the ways in which curriculum materials can be used to plan and enact lessons. With regard to knowledge of science assessment (i.e., in particular, knowledge of methods for assessing student learning), we articulated specific considerations for teachers when deciding what assessment methods to use. Finally, with regard to knowledge of science instructional strategies (i.e., in particular knowledge of subject-specific strategies for any topic), we added the idea that teachers need instructional strategies for helping students develop both
their understanding of science topics and their abilities and understanding of scientific inquiry. Additionally, teachers need knowledge not only of different types of strategies for enacting science instruction but also of the ways in which they can productively use these strategies in practice.

Additionally, the findings from this study deepen the field’s theoretical knowledge about preservice elementary teachers’ PCK for science teaching by highlighting alternative ideas that novice teachers may have about the different components of this knowledge domain. Many preservice and new teachers have limitations in their PCK for science teaching (Abell & Roth, 1992; Lederman et al., 1994; van Driel et al., 1998; Zembal-Saul et al., 2000). This study highlights particular alternative ideas within preservice teachers’ knowledge of science assessment, science curriculum materials, and science instructional strategies. These limitations in preservice teachers’ PCK for science teaching may impact their ability to meet the ambitious learning goals entailed in reform-oriented science teaching. Thus, it is important that science teacher educators provide preservice teachers with additional support in learning how to teach.

Despite these limitations in preservice teachers’ PCK for science teaching, it is important to note that developing a knowledge base for science teaching takes time and that the preservice teachers in this study were just beginning to learn about what it means to teach science. Thus, it is reasonable that the preservice teachers struggled in the ways that they did as they developed their PCK for science teaching during the course of just one semester. Additionally, the preservice teachers likely had additional strengths with regard to their PCK for science teaching than what the analysis tasks measured in this study since these tasks were designed to measure preservice teachers’ knowledge-in-action and not simply their knowledge.

**Design Implications for Science Teacher Education**

This study’s findings also offer important insights to science teacher educators, in terms of the types of supports and experiences they need to provide preservice elementary teachers in order to help them develop and apply their PCK for science teaching in the analysis of science curriculum materials. Specifically, teacher educators might have beginning teachers first explore aspects of PCK for science teaching that build upon their own goals for and understandings of science teaching. Leveraging preservice teachers’ productive ideas about science instruction may promote their knowledge of science teaching, and in turn, their ability to apply that knowledge in productive ways to the analysis of science lesson plans. Subsequently, teacher educators might help beginning teachers identify gaps and limitations in their PCK for science teaching and then introduce them to new ideas for science teaching—foregrounded in reform-based criteria. This can help them develop a more robust understanding of different dimensions of PCK for science teaching and more extensive ideas for analyzing science lesson plans.

Additionally, the preservice teachers in this study developed an improved understanding of PCK for science teaching when they had the opportunity to consider the same dimensions of this knowledge domain (i.e., the same criteria) using multiple lesson plans. Thus teacher educators should enable preservice teachers to practice applying the same criteria using different science lesson plans. This can provide them with the opportunity to visualize the criteria in different ways and thus develop their understanding of the different components of PCK for science teaching foregrounded in the criteria.
**Future Research Directions**

This study characterized preservice elementary teachers’ PCK for science teaching and their ability to apply this knowledge in the analysis of science curriculum materials. These descriptions shed light on strengths in their understandings, areas in need of support, and benefits and limitations of using reform-based criteria as scaffolds. However, it is important to note that the findings and subsequent recommendations from this study are based on only one science methods course. Additional studies situated within other methods courses are needed in order to understand how the findings from this study extend to other preservice teachers and to increase the reliability of the recommendations proposed. Conducting additional studies within different contexts is also likely to lead to the identification of additional struggles preservice teachers face in developing their PCK for science teaching and applying their understandings in the analysis of science curriculum materials. Additionally, other leverage points and instructional strategies may also be elucidated for supporting preservice teachers’ knowledge development.
References


Appendix A
Example of Lesson Plan Analysis Assignment

Lesson Plan Analysis Assignment <#>: <Lesson Title>

Teachers modify lessons to better meet their own teaching style and the needs of their students. Applying criteria in your analysis of lesson plans can help you think about how you can make productive changes to lessons you find – a major focus of this course. The purpose of this assignment is to help you (a) think about how you can use criteria to identify strengths and weaknesses in a lesson plan and (b) begin to think about how you can make changes to lessons in order to foster inquiry and attend to kids’ ideas.

Teachers possess ideas about effective science teaching and they use those ideas to determine whether curriculum materials have those characteristics or not. To do a good job at analyzing curriculum materials, you too need to have some criteria by which you can judge the materials. In this assignment, you will have the opportunity to practice analyzing a lesson plan with regard to 3 criteria that you’ve recently learned about in class. These criteria focus on key aspects of effective science teaching.

In class, you’ve also identified important characteristics of these 3 criteria. These characteristics will help you judge how well the lesson plan meets each criterion. Below are the 3 criteria (numbered) and their characteristics (lettered) that you will use in this analysis:

1. Attending to learning goals
   A. Do the learning goals address both science content and inquiry?
   B. Are the learning goals grade-appropriate & aligned with standards documents?
   C. Are the learning goals aligned with activities and assessments?

2. Establishing a sense of purpose
   A. Does the lesson help teachers make the purpose of the activity explicit to students?
   B. Is the purpose meaningful to students and anchored in the lives of learners?
   C. Does the lesson help the teacher connect the purpose of the activity to what students have been learning about thus far in class?

3. Eliciting students’ ideas at the beginning of a lesson
   A. At the beginning of the lesson, does the lesson enable the teacher to elicit students’ ideas about the new content and predictions about the phenomena?
   B. Does the lesson ask students to give explanations for their ideas and predictions in order to help teachers probe beneath students’ responses?
   C. Does the lesson provide opportunities for students’ ideas and predictions to be recorded and shared with others in the class?

In your CASES journal, analyze the lesson plan with regard to each criterion by responding to the questions above. As you respond to each question, make sure to include the following things:

- Decide whether the lesson plan meets or does not meet the indicator. Explain why you think this and provide examples from the lesson plan to support your ideas.
- For the weaknesses that you identify, describe specific changes you could make to improve the lesson plan.
Appendix B
Example of Analysis Task and Lesson Plan Description in Reflective Teaching Assignment

Reflective Teaching Assignment [#1]

Part 1a: Lesson Plan Analysis Task

Teachers possess ideas about effective science teaching and they use those ideas to determine whether curriculum materials have those characteristics. To do a good job at analyzing curriculum materials, you need to have some criteria by which you can judge the materials. In this part of the assignment, you will analyze your lesson plan with regard to 3 criteria of your own choosing. You can select criteria that you’ve recently learned about in class or select your own criteria.

Use the following questions to guide your description and use of the criteria in your analysis.

For each criterion, answer the following questions:
1. What criterion did you choose?
2. Why did you choose to use this criterion in your analysis?
3. What are the indicators for this criterion? (Identifying indicators will help you identify important characteristics of the criterion that you can use to guide your analysis.)
4. For each indicator: Does the lesson plan meet the indicator? Explain why you think this and provide examples from the lesson plan to support your ideas. For the weaknesses you identify, what specific changes could you make to the lesson to better meet the indicator?

Remember to address these four questions for each of the three criteria.

Criterion #1

Criterion #2

Criterion #3
Part 1b: Revised Lesson Plan

Title of Lesson:

Grade level:

Length of lesson:

Overview:
- Provide a short description of the lesson:

Learning Goals:
- What do you want students to know and be able to explain at the end of this lesson?
- What do you want students to be able to do (with regard to inquiry)?

Connections to Standards/ Benchmarks/ Curriculum:
List the standards as written in the Michigan Curriculum Framework (or the Science Grade Level Content Expectations document, which clarifies the MCF), National Science Education Standards, or AAAS Benchmarks. Write down what chapter, section, and grade level you drew the standard from, in addition to the source itself.

Context of Lesson:
How does the lesson fit within the unit as a whole?

Materials:

Students’ Ideas:
- What ideas should students understand before beginning the lesson?
- What potential alternative ideas might students hold?
Teaching Strategies: Intro
Think about the following questions as you describe how you will introduce the lesson:
- How will you connect this lesson to the previous one?
- What is your investigation question or problem for the lesson?
- How will you elicit students’ existing ideas?

Teaching Strategies: Main Lesson
Think about the following questions as you describe the steps of the lesson:
- What will you do? What will your students do? Do not assume someone reading your lesson plan has access to the original lesson plan! Be clear and complete.
- Do the activities support students in engaging in scientific inquiry? How will you help students make predictions? Collect data and make observations? Look for patterns in data? Build evidence-based explanations?
- What will you do to manage materials/movement around the classroom/transition?
- Do the activities support students of all achievement levels? What will students do who finish an activity early? Who do not finish?

Teaching Strategies: Wrap-up
Think about the following questions as you describe how you will close the lesson:
- What explanations will your students construct?
- How will you help students connect their explanations to the investigation question?
- What specific questions will you ask students to help them interpret their in-class experiences and connect them to scientific ideas and their own ideas about the phenomena? What questions will you ask to help students progress from their initial ideas and predictions elicited at the beginning of the lesson?
- How will you help students connect to previous and subsequent science lessons?

Assessment:
- What evidence will you gather to let you know if your students achieved the learning goal(s)? How will you collect this information?
- Does your assessment focus on understanding of key ideas and practices and require application of ideas?
- Are you able to assess each student’s understanding?
Appendix C

Examples of the Accurate and Alternative Understandings of the Reform-Based Criteria in the Lesson Plan Analysis Assignments

**Criterion 1—Attending to Learning Goals**

1a—Including inquiry and content learning goals. Nearly half of the preservice teachers (10/24) understood what it meant to analyze learning goals to see if they addressed both science content and inquiry. In the first lesson plan analysis assignment, the lesson plan focused on helping first and second graders learn about waterproofing as one of the properties of materials by having them test the ability of different materials to keep a cotton ball dry. The lesson plan contained two learning goals focused solely on content: Students will identify waterproofing as one of the properties of materials, and students will distinguish between objects that are waterproof and those that are not. These preservice teachers recognized that the lesson plan did not include inquiry learning goals, leading them to adapt incorporate them in the lesson. Amelia illustrates this analysis in the following excerpt:

> The learning goals listed in the lesson plan address science content. The first goal asks students to identify one useful property of materials, a learning goal that spans science topics and grade levels. The second goal asks students to classify objects according to a certain property, another learning goal that spans the entire science curriculum. However, the learning goals do not address inquiry. Neither learning goal addresses the inquiry process students will use in class. As the lesson stands now, an appropriate inquiry learning goal would be that 'Students will construct charts of and summarize their findings for the purpose of communicating with others' (aligned with MCFSC standard I.1.e6). Similarly, another learning goal would be that 'Students communicate their findings with others using data charts and graphs.' (Amelia, Lesson plan analysis assignment 1)

Even though several preservice teachers understood how to identify content and inquiry learning goals, one common alternative understanding predominated among the preservice teachers. Several individuals decided to examine whether the lesson plan itself was inquiry-oriented to determine if the learning goals addressed inquiry. Thus, in their analysis, they concluded that one or both of the stated learning goals addressed inquiry just because the lesson plan happened to be inquiry-oriented, even though the learning goals themselves did not include a focus on inquiry. The following example shows how Susan looked at the lesson plan itself to determine if the learning goals addressed inquiry. She writes:

> Yes, learning goal 1 addresses science content. Students explore properties of objects throughout the lesson. Learning goal 2 addresses inquiry. Students will be able to make conclusions about whether or not certain objects are waterproof. They achieve this learning goal through the actual classroom activity involving the different materials, water and a cotton ball. Also, throughout the activity students are working as scientists. They work collaboratively in groups as scientists often do and record their data in an organized way. (Susan, Lesson plan analysis assignment 1)

This alternative understanding reflects that several preservice teachers did not understand the difference between having explicitly stated learning goals that address inquiry and having a lesson plan that includes inquiry practices. Interpreting the indicator in this way may result in missed opportunities for helping students develop their inquiry understandings and abilities.

1b—Connecting learning goals to standards. A third of the preservice teachers (8/24) understood what it meant for the learning goals to be grade appropriate and aligned with standards documents. In their analysis, these preservice teachers used the science standard documents for the respective grade level to determine if learning goals were in fact grade appropriate and aligned with the standards, and they found that they were. Ashley demonstrates this correct application of the indicator, writing:

> The goals of the lesson address the science content standards that students of this grade should learn. According to the National Science Education Standards: Standard B, K-4 students should develop an understanding of the properties of objects and materials and the learning goals of this lesson indicate that students will be learning about a particular property of materials. This property is that of being waterproof...The learning goals are grade appropriate because as I stated earlier the content that they are
learning aligns with the National science education standards for K-4 students. (Ashley, Lesson plan analysis assignment 1)

Even though some preservice teachers correctly applied this indicator, most of the preservice teachers had one of two alternative understandings. With regard to grade appropriateness, some preservice teachers did not use the standards to determine if the learning goals were appropriate for first and second graders—the grades targeted by the lesson plan that they had received. Instead, they determined if the learning goals were grade appropriate by using only their teacher sense. For example, Jessica decided for herself if she thought the learning goals were appropriate for early elementary students, writing, “I do believe the learning goals are grade-level appropriate because the inquiry is something that is manageable for second graders, while still providing them with the experience of developing an understanding of waterproof materials” (Lesson plan analysis assignment 1). Jackie also used her own intuition to determine if the learning goals were grade-appropriate but arrived at a very different conclusion. She wrote:

[I]t seems that these learning goals might be a bit simplistic for students of this age and wouldn't really challenge them to engage in inquiry and discovery. Many young students already know that waterproofing is a characteristic of some objects, and probably already have some understanding of which objects possess this trait. I think it might be more beneficial to have learning goals that required them to dig deeper into the concept of waterproofing and to understand how it works and why certain object have the property. (Jackie, Lesson plan analysis assignment 1)

By not relying on the standards to inform their ideas about grade-appropriateness, these preservice teachers made different judgments about whether the learning goals were appropriate for first and second graders. Relying on one’s own intuition solely for making decisions about what learning goals are appropriate or not appropriate for particular students may result in teachers underestimating about what students are capable of learning or engaging students in science content about which they are not prepared to learn.

With regard to the standards, some preservice teachers had an alternative understanding about how to determine whether learning goals are aligned with standards documents. They thought they could just assume that the lesson plan would automatically be aligned with some set of standards and that it was not necessary for them to check if this was the case. Chelsea exemplifies this approach, writing:

As for the science content learning goal, I also feel that it is well-aligned, since it fits well within the context of the unit as a whole (properties of matter), and I am assuming that the entire unit must be meeting some sort of state and/or local standards or benchmarks. (Chelsea, Lesson plan analysis assignment 1)

This typical example shows that some preservice teachers mistakenly thought the lesson plans that they would be given would necessarily be aligned with their state’s or district’s standards. Making this assumption may result in missed opportunities for students to learn about particular science content and inquiry practices.

1c—Aligning lesson and assessment to learning goals. Nearly every preservice teacher (22/24) understood what it meant for the learning goals to be aligned with the activities and assessments in the lesson plan. In their analysis, most of the preservice teachers stated that the learning goals in the lesson plan were aligned with both the activities and assessments and provided evidence from the lesson plan to support their claim. The following example illustrates this systematic check for alignment between learning goals, the lesson activities, and assessment:

The learning goals are aligned with the activities because students are looking at several different materials to see if they possess the property of being waterproof. Also, they are making a chart in groups and as a class that distinguishes the waterproof materials from the not-waterproof materials. The assessments do measure the learning goal that students should be able to distinguish between waterproof materials and those are not by asking students to determine what materials are waterproof during the investigation, finding two more materials at home that are waterproof, and in the ‘after the investigation’ activity. (Jackie, Lesson plan analysis assignment 1)

Jackie, like most of her peers, understood how to examine a lesson plan and its assessment for alignment with its stated learning goals

Criterion 2—Establishing a Sense of Purpose

2a—Making the purpose explicit to students. Most of the preservice teachers (22/24) understood how to analyze a lesson plan with regard to making the lesson purpose explicit to students. In their analysis, the
Preservice teachers recognized that the purpose of the lesson was to help kids learn about another property of materials (waterproofing) and that the lesson helped the teacher make this purpose explicit to students. They pointed to different (but consistent) kinds of evidence to support this claim. For example, Jessica wrote:

I believe the lesson does help teachers make explicit the purpose of the activity. Just the opening question introduces the idea of something being waterproof as the students think about how they can keep a cotton ball dry. Also, brainstorming ideas of how to keep something dry is a way to explicitly get students thinking about the concept of waterproofing. (Jessica, Lesson plan analysis assignment 1)

This example shows that the preservice teachers experienced little difficulty in determining whether the lesson purpose was made explicit to students or not.

2b—Making the purpose meaningful to students. Over half of the class (14/24) understood how to help students see the lesson purpose as meaningful and anchored in their everyday lives. The stated lesson purpose—to keep a cotton ball dry in the rain—was not likely to be meaningful and relevant to students’ everyday lives. In their analysis, these preservice teachers addressed this weakness by adding a more meaningful and contextualized investigation question to the beginning of the lesson, for example, as Karen wrote:

I think that [the purpose] could be more meaningful to students if students were first given the prompt: How can I stay dry when it is raining out? Or What is the best way to stay dry when it is raining out? That way this lesson may be more explicit to students when they understand that seeing what keeps the cotton ball dry could also help them see how they can stay dry in a rainstorm. (Karen, Lesson plan analysis assignment 1)

Even though some preservice teachers understood what it meant to provide students with a lesson purpose that is anchored in their everyday lives, other preservice teachers had an alternative understanding of this indicator. These individuals thought it was sufficient to analyze the lesson purpose to see if it was meaningful to the lives of learners without actually analyzing the lesson plan itself to see if helped students see the purpose as meaningful. Jackie illustrates this alternative understanding in her discussion of the lesson purpose on waterproofing, writing:

The purpose of this lesson is quite relevant to students and is something that they will encounter in their lives. Many probably already have a lot of experiences with waterproof and non-waterproof material, although they may not have thought of it in that way at the time. Wearing raincoats or using umbrellas to keep themselves dry, or forgetting their raincoats and getting wet in their cotton t-shirt are experiences that almost all children can relate to. They have also probably encountered situations with food or drink in certain containers, which relates to waterproofing as well...All of this information is relevant to the student's lives. (Jackie, Lesson plan analysis assignment 1)

These preservice teachers thought that just because the lesson purpose was meaningful and anchored in the lives of learners that students would automatically see it as such. Interpreting the indicator in this way may result in missed opportunities for them as teachers to help their students see how lessons relate to their everyday lives.

2c—Connecting the purpose to previous lessons. Half of the class (12/24) understood what it meant to analyze a lesson plan with regard to how well it helped students see the lesson as connected to previous lessons. In their analysis, they recognized that the lesson plan did connect with what students had been learning about in class but did not help students see these connections. To address this weakness, most of the preservice teachers suggested adding either a review session or teacher explanation to the beginning of the lesson to make these connections more explicit, as Melanie illustrates here:

[B]efore this lesson began to unfold, I think it would have been very useful for the teacher to do a quick review or summary of what they have been learning as far as the different properties of matter, have them name the properties they've learned thus far, and then ask if they think they know of another property. (Melanie, Lesson plan analysis assignment 1)

The other half of the class had an alternative understanding of this indicator. They analyzed the lesson plan in terms of how well it connected with what students had been learning about in class, not in terms of how well it helped students recognize these connections. Morgan demonstrated this understanding, stating that the lesson did help the teacher connect the purpose of the activity to what students have been learning about thus far in class. She wrote, “The purpose of the activity in this lesson is connected with the learning so far. They have been looking at observable characteristics of materials and waterproofing is another observable characteristic” (Lesson plan analysis
assignment 1). These preservice teachers assumed that just because a lesson was connected with previous lessons that these connections would be obvious to students. Possessing this alternative understanding may result in missed opportunities for them to help their students see the connections between lessons.

**Criterion 3—Eliciting Students’ Initial Ideas and Predictions**

3a—Eliciting ideas and predictions at start of lesson. On the first lesson plan analysis assignment, two-thirds of the class (16/24) understood how to examine a lesson plan for how well it helped teachers elicit students’ ideas about the new content and their predictions about the phenomena. In their analysis, these preservice teachers attended to both students’ ideas and predictions in their response and recognized that the lesson did, in fact, elicit both. Lisa demonstrates this understanding, writing:

Students are given the opportunity to reflect on their ideas before the lesson begins when they are asked to draw a picture of how one could protect a cotton ball in the rain. In addition, they are given a space in which to record their predictions regarding whether each material being tested in the investigation will be waterproof or not. (Lisa, Lesson plan analysis assignment 1)

Therefore, the majority of the preservice teachers had an accurate understanding of this indicator.

3b—Eliciting explanations for students’ ideas/predictions. Two-thirds of the preservice teachers (16/24) understood how to analyze the lesson plan to have students give explanations for their ideas and predictions. In their analysis, they recognized that the lesson did not provide opportunities for students to give explanations and thus added prompts for explanations to the student worksheets and whole class discussion. Amelia illustrates these modifications, writing:

[S]tudents are not asked to explain their ideas and predictions. They are simply asked to draw a picture in their journals and mark boxes on their charts. Students should be asked why they would use that item or material to keep a cotton ball dry in the rain and why they think the cotton ball in their investigation will or will not get wet. Students can explain in writing or by communicating verbally with their classmates and teacher. In my proposed journal questions, students must explain why they believe what they believe. I would also have students verbalize the reasoning behind their predictions to their group members and other classmates. (Amelia, Lesson plan analysis assignment 1)

This typical example shows that most of the preservice teachers understood how to identify whether students provided explanations for their ideas and predictions and made appropriate modifications, thereby providing opportunities to probe beneath students’ responses.

3c—Having students record and share their ideas/predictions. Two-thirds of the preservice teachers (16/24) understood how to provide opportunities for students to record and share their initial ideas and predictions about phenomena. In their analysis, they recognized that the lesson provided opportunities for students to record their ideas and predictions. Here, Emily describes these aspects of the lesson plan, writing:

At the beginning of the lesson, the students do have the opportunity to record their ideas and predictions. They fill out the Before the Investigation sheet which gives them the chance to draw a picture of what they would use to keep a cotton ball dry in the rain. They are also given the opportunity to fill out the Waterproofing Data Table which allows them to predict which items will keep a cotton ball dry in the rain. (Emily, Lesson plan analysis assignment 1)

In addition to identifying these strengths in the lesson plan, these preservice teachers also identified some weaknesses with regard to the indicator. They recognized that the lesson did not enable the students to share their ideas and predictions with others. They addressed this weakness by providing opportunities for students to share their ideas and predictions in small groups or as a whole class discussion, as shown in the following example:

While the students did have the opportunity to record their ideas and predictions in their science journals, they did not get a chance to share their thoughts with the rest of their class, or even with a small group of peers. I think that the lesson should include either a whole class discussion…or they should engage in some pair or small group sharing time, during which they can talk to one another about their ideas and see what their peers think as well. Cooperative learning can be very beneficial in a lesson such as this one, since all of the students have such different prior experiences, and many of them may have different experiences that can contribute to their overall understanding of this scientific concept. (Chelsea, Lesson plan analysis assignment 1)
Overall, the majority of the preservice teachers had a strong understanding of this indicator, recognizing if students had the opportunity to record and share their ideas and predictions and making adaptations to the lesson plan to compensate for any of its weaknesses.

**Criterion 4—Providing Experiences with Phenomena**

4a—Providing multiple experiences with phenomena. In their second lesson plan analysis assignment, over half of the preservice teachers (15/24) understood how to determine if students had the opportunity to experience the scientific phenomena in multiple ways, whether through first-hand or vicarious experiences or even through instructional representations. They demonstrated this understanding in their analysis of the second lesson plan, which involved engaging second and third graders in investigating the seed dispersal methods of different types of seeds. In their analysis, they asserted that the lesson only provided one experience with phenomena (the hands-on activity) and adapted the lesson to include another experience for students, as illustrated in Lisa’s analysis:

This lesson revolves around one experience with phenomena: the hands-on experiment with seeds. If I were to change this lesson, I would integrate a video or images of seeds in motion in everyday settings (a bur on a dog, helicopters). Students are more likely to make connections to a phenomena when they see it at play in its natural environment than in a lab (Oh! My dog gets burs in her fur…) (Lisa, Lesson plan analysis assignment 2)

Even though many of the preservice teachers understood this indicator, over a third of them (9/24) had an alternative understanding. They interpreted multiple experiences with phenomena to mean the different elements of the lesson plan (e.g., completing the worksheet, conducting the hands-on activity, participating in concluding discussion). For example, Shelley mistakenly pointed to different components of one experience with phenomena as evidence that the lesson plan provided students with multiple opportunities to experience the phenomena. She wrote, “Yes. Kids are possibly working outside for part of the lesson, they are interacting with the different types of seeds, they are experimenting with these materials in air, water, clothes, drawing pictures, filling in a chart” (Lesson plan analysis assignment 2). This excerpt shows that some of the preservice teachers did not understand what counted as an experience with phenomena. Failing to understand this pedagogical idea may result in missed opportunities for students to experience a range of phenomena, and in turn, see science ideas as having explanatory power.

4b—Having students record data. All of the preservice teachers understood how to provide opportunities for students to record their data. In their analysis, they recognized that the lesson plan asked students to complete a chart describing the experimental results of how different types of seeds traveled. Carmen exemplifies this understanding of the indicator, writing:

Students are asked to create drawings of each type of seed that they received as well as write the name of the seed on their science worksheet. Students are also asked to record the test results of which phenomena can carry their seeds on their worksheets. I do feel that students are appropriately asked to record their data and observations throughout this lesson. (Carmen, Lesson plan analysis assignment 2)

Not only did the preservice teachers assess whether the lesson plan enabled students to record their data, but over a third of them (9/24) further analyzed the lesson plan to determine how well it did this. For example, some of the preservice teachers adapted the worksheet so that students would not only draw the different types of seeds that they tested but also describe the seeds’ characteristics in words, as exemplified by Teresa, who wrote:

On the student worksheet students are given a spot to draw pictures of the seeds and to record the way that the seed travels. I think that these are both crucial to the lesson. However, one thing that I would like to add to this sheet is a place to describe the characteristics of the seed. I would place this observation after drawing the seed. This way, students first really look at and study the seed and then must find words or descriptions for what they see. (Teresa, Lesson plan analysis assignment 2)

Overall, the preservice teachers understood how to provide structured opportunities for students to record their data, with some individuals further analyzing the quality of these data recording opportunities—exceeding the expectations of this indicator.

4c—Having students share and interpret their data. Most of the preservice teachers (20/24) demonstrated an understanding of how to engage students in sharing their results and looking for patterns in the data. In their analysis, they recognized that the lesson plan met this indicator, writing, for example:
The lesson does provide students with the opportunity to share their results and look for patterns in the data. The section entitled ‘Reflect and Discuss’ allows them the opportunity to do so. The students share their results by talking about what they have noticed and learned from their experiments. The students are looking for patterns in the data by making connections between physical characteristics and likely dispersal type. (Emily, Lesson plan analysis assignment 2)

Additionally, about half of these preservice teachers (9/24) analyzed the lesson plan not only in terms of whether the lesson plan included these tasks but also how well they engaged students in these tasks. For example, Claire adapted the lesson to have each group of students share their results with the class in order to look for patterns in the data more systematically. She wrote:

The lesson does not explicitly give opportunities for students to share their results and look for patterns in data; it does, however, give students a chance to share their overall conclusions in the large group. Having each group share their results with the whole-class might help the class look for patterns inherent across groups, and help students test their conclusions against those of their classmates. (Claire, Lesson plan analysis assignment 2)

In general, most of the preservice teachers demonstrated an understanding of how to engage students in sharing and interpreting their data. Even more, some individuals went beyond the stated indicator by also analyzing the quality of these tasks.

**Criterion 5—Promoting Sense Making**

5a—**Having students develop evidence-based explanations.** Two-thirds of the preservice teachers (16/24) understood that constructing a scientific explanation entailed using evidence in support of a claim, and in turn, successfully recognized whether or not the lesson plan engaged students in this scientific practice. In their analysis, the preservice teachers noted that the whole class discussion at the end of the lesson provided students with the opportunity to use their investigation results to support their claims about how the seeds from their playground were dispersed. Michelle makes this observation in the following excerpt:

During the final discussion, students are prompted to use their results and observations to support their idea about why they think the tree's seeds traveled the way they think. Students are held accountable for explaining their claims by using what they learned from their investigations. (Michelle, Lesson plan analysis assignment 2)

In addition to demonstrating this understanding, a third of the preservice teachers (8/24) further analyzed the lesson plan to see if provided an opportunity for every student to develop a scientific explanation. For example, Debbie engaged in this additional analysis, writing:

In the last part of the discussion the students are to ‘use the results from the investigation and their observations of the seeds’ characteristics to explain why they think the tree's seeds travel in the way that they describe.’ So this definitely encourages them to use the evidence they collected to support their claims/explanations! By having the whole class discussions it allows students to voice their explanations, however not all students will be heard (because of time constraints) so perhaps by having a journal for the students to write in would allow all students to participate in this part of the lesson. (Debbie, Lesson plan analysis assignment 2)

This example shows that the preservice teachers not only looked for opportunities for students to construct scientific explanations but that some of them also checked to see if every student had this opportunity—an expectation that surpassed the conditions of the stated indicator.

5b—**Asking guiding questions to facilitate sense making.** Most of the preservice teachers (21/24) understood how to analyze the lesson plan for guiding questions to help students interpret their experiences with phenomena and connect them to scientific ideas. As written, the lesson plan did not provide the teacher with questions to guide students’ understanding during the concluding discussion. These preservice teachers recognized this omission, but only half of them (12/24) added discussion questions to the lesson. The following example provides a set of questions that one preservice teacher developed. Karen wrote:

There is no true list of questions that a teacher could use in a discussion. I think that this can be problematic for a teacher since discussions are sometimes difficult to manage and plan for. The lesson does provide the initial study question and two supplemental questions at the beginning of the lesson, however it does not
include any final questions in the end of the discussion. I think that some questions that could be helpful include:

- What did you notice in your observations of seeds?
  - What did the seeds look like?
  - What did they feel like?
  - Did you notice any similarities or differences in your seeds?
- What did you notice in your investigations?
  - Where their [sic] any patterns you saw?
  - What was challenging/difficult
- Did you notice any patterns between seed shape/design and the way that it moved?
  - What does that tell us about the seeds?
  - Which seeds move by floating? Wind? Animals?
- Look at your first ideas about seeds: Is there anything you would change?
  - Take the time to write down your new changes? [sic] How did your ideas change?
  - Why did you change your ideas? What did you do in the activity that changed your activities?

(Karen, Lesson plan analysis assignment 2)

The other preservice teachers who recognized that the lesson plan did not include guiding questions for the final discussion made no adaptations. The task of designing discussion questions to guide an inquiry-based discussion may have been too difficult for them to complete. For example, Leah wrote, “The teacher is given little in the way of a list of questions, in order to help facilitate the discussion and the students' thinking” (Lesson plan analysis assignment 2). Similarly, Morgan noted the omission of discussion questions but did not adapt the lesson plan to compensate for this weakness, writing, “The lesson does not provide the teacher with a list of questions to help students interpret their experiences with phenomena and connect them to scientific ideas. The teacher has to come up with his or her own questions” (Lesson plan analysis assignment 2).

5c—Asking students to revisit their initial ideas. Most of the preservice teachers (22/24) understood how to analyze the lesson plan in terms of revisiting students’ initial ideas. In their analysis, they recognized that it had students examine how their initial ideas have changed and in what ways. Emily illustrated this understanding in the following passage:

The lesson does provide opportunities for students to revisit their initial ideas about the new content. At the end of the lesson, the teacher asks the students if they have changed their mind about how they think trees got into their playground. This not only allows the students to revisit their initial ideas but also provides a way of making the lesson have more of a purpose. (Emily, Lesson plan analysis assignment 2)

Overall, the preservice teachers tended to demonstrate an understanding of this indicator.

**Criterion 6—Assessing Student Learning**

6a—Assessing content understanding and inquiry abilities. In their third lesson plan analysis assignment, around one-third of the preservice teachers (9/24) understood how to analyze a lesson plan to see if it provided assessments that measured students’ understanding of inquiry and content learning goals. The lesson plan for this assignment had fifth grade students learn about friction by testing how far a toy car can travel on a variety of surfaces. In their analysis of this lesson plan, the preservice teachers systematically checked to see if the lesson plan enabled the teacher to assess each learning goal and found that the learning goals were assessed through a combination of three different types of assessments—whole class discussion, teacher observation, and student worksheets. For example, Michelle explicitly detailed how the assessments aligned with the content and inquiry learning goals, writing:

The lesson does provide teachers with assessments that provide them with opportunities to assess students' inquiry skills as well as students' understanding of science concepts. The science notebook page gives students a chance to make and record their predictions, as well as a place to record their actual findings so that at the end students can compare their findings with their predictions and revise their initial ideas. Additionally, the end of class discussion questions that ask why (the car stopped at different distances on the different surfaces) and ask students to use evidence to support their answers allow teachers to assess students’ content understandings and ability to give explanations. (Michelle, Lesson plan analysis assignment 3)
Even though some preservice teachers understood how to check for alignment between the learning goals and the assessments and correctly assessed the lesson plan based on this indicator, the majority of the preservice teachers (15/24) did not. The most common alternative understanding was the idea that the lesson plan simply needed to include an assessment in order for the indicator to be met. They assumed that the assessments would automatically be aligned with the learning goals, leading them not to articulate the connections between the assessments and learning goals. Amelia demonstrates this alternative understanding, writing, ‘‘[T]he lesson provides teachers with assessments to assess both science content and inquiry learning goals. These can be found under ‘Evidence.’ The teacher is to use the worksheet, class discussion, and observations to see if students meet the learning goals” (Lesson plan analysis assignment 3). Possessing this alternative understanding may result in missed opportunities to assess some learning goals, limiting what they as teachers will be able to say about what students understand and are able to do.

6b—Assessing each student’s understanding and abilities. Only three preservice teachers (3/24) understood the importance of having each student demonstrate both his or her content understanding and inquiry abilities. As written, the lesson plan allowed each student to make predictions and record results but not to develop explanations and express their content understandings. These preservice teachers addressed this weakness by adapting the worksheet to allow each student to record their content ideas and explanations. For example, Teresa wrote:

I feel that the assessment does for the most part allow teachers to assess students’ inquiry skills. They are assessed on their predictions when they record them on their notebook page and have to record their reasoning behind it. Students also have to actually carry out the experiment and record the information that they receive in a chart. The teacher can check this again by looking at the student notebook page. The only thing that the teacher may not be able to assess is the evidence based explanations that students make. At one point students are asked to share this in the whole class discussion, however, everyone will not get to share. There is also not a place on the worksheet for this. For this reason, I would add some of questions from discussion such as, ‘Which surface had the most friction? What is your evidence?’ onto the sheet. This way the teacher can view every student’s response instead of just of a few. I also think that the teacher does a nice job of assessing students understanding of science ideas in the whole class discussion… However, I am not sure that she can assess all of her students’ knowledge in this way. She cannot hear from every student or else the discussion would take forever. For this reason, I would add more of the discussion questions to the worksheet or have them write a journal entry after discussing some of the things that students learned. (Teresa, Lesson plan analysis assignment 3)

Aside from these three preservice teachers, the rest of the class (21/24) had an alternative understanding of this indicator. One perspective entailed the idea that it is only important for each student to express their content understandings but not their inquiry abilities. Thus, in their analysis, the preservice teachers with this perspective only commented on whether the lesson provided opportunities to assess each student’s content understandings, writing, for example:

As far as content is concerned, there is nothing really that lends itself to assessment of students’ content learning. Another question could be added to the notebook page that asks students at the end of the activity why the cars went as far as they did or why they saw differences. The end of class discussion addresses content, but because it's a discussion it might not be representative of every students [sic] thinking. Alternative ideas may go unnoticed because that student does not contribute to the discussion. (Susan, Lesson plan analysis assignment 3)

Focusing only on assessment of each student’s content understandings may result in missed opportunities to assess each student’s inquiry abilities, and in turn, to help each student improve their understandings of and abilities necessary to do inquiry.

Other preservice teachers who had an alternative understanding of this indicator assumed that use of the science worksheets would ensure that the teacher could assess students with regard to all of the learning goals. Thus, in their analysis, these preservice teachers asserted that the teacher could assess each student’s content understanding and inquiry abilities by solely using the student worksheet. Chelsea demonstrates this alternative understanding, writing, “In the best way that it could, I think that yes, this lesson does allow each student to demonstrate his or her understanding and skills. Each student is responsible for his or her own student notebook page” (Lesson plan analysis assignment 3). Here, these preservice teachers did not realize that the worksheet only
enabled the teacher to assess students’ ability to make predictions and record results, not their content understandings and ability to develop scientific explanations. Assuming that teachers can rely exclusively on provided worksheets to assess all of their students’ content understandings and inquiry abilities may result in missed opportunities for them to assess what students have learned in their science investigations.

**6c—Asking students to apply their ideas to a new task.** The majority of the preservice teachers (18/24) understood how to identify opportunities for students to apply their ideas to a new task or situation. In their analysis, they recognized that the lesson plan did not allow students to apply their newly developed ideas and thus adapted the lesson to compensate for this weakness. For example, Jackie suggested two ways to have students apply their ideas. She wrote:

> Something that I think this lesson plan is lacking is an assessment that requires students to apply their ideas to a new task or situation… Giving students examples of a few other surfaces and asking them to predict how far the car would go on those surfaces and to support it with information they had learned that day would work. Another way would be to give students a scenario and have them describe how friction played a role in the situation. (Jackie, Lesson plan analysis assignment 3)

As this example shows, most preservice teachers displayed an understanding of this indicator.

**Criterion 7—Making Science Accessible for All Students**

**7a—Attending to the needs of individual students.** Only four preservice teachers (4/24) understood how to consider the needs of individual students or groups of students in their analysis. They modified the lesson plan to accommodate for the needs of specific groups of students, including students with disabilities, English language learners, and special needs students. For example, Amelia addressed the needs of two particular groups of students, writing:

> The lesson does not offer ideas for paring down the lesson for students with disabilities or making the lesson more challenging for high-achieving students. I would have an alternative worksheet for or assign student buddies to students with disabilities, depending on the nature of the disability. I would also have a list of more challenging questions about the investigation for high-achieving students to consider or ask them to research friction on the computer if they finished early. They would need to find two interesting facts about friction to share with the rest of the class during the wrap-up discussion. (Amelia, Lesson plan analysis assignment 3)

Aside from these preservice teachers, the rest of the class (20/24) had an alternative understanding of this indicator. They analyzed the lesson plan to see if the teacher had the opportunity to help students, in general, rather than specific students or groups of students. Thus, in their analysis, they stated that the teacher had the opportunity to attend to the needs of individual students by modeling how to do the experiment, enabling students to work in groups, or circulating while students worked on the experiment, as illustrated in the following example:

> I think so, the fact that the teacher models the experiment first giving students explicitly what they need to do sets them up to succeed...Furthermore, small group work is great and allows students to help each other out. The teacher can move around between the groups to help with what their doing. (Melanie, Lesson plan analysis assignment 3)

This excerpt exemplifies the alternative understanding that most of the preservice teachers had with regard to this indicator. Focusing only on a class as a whole rather than on individual students may result in missed opportunities for them as teachers to attend to the needs of every student and thus to help all students experience success in learning about science.

**7b—Connecting science ideas to personal/cultural experiences.** Most of the preservice teachers (19/24) understood what it meant to analyze a lesson plan to see if it allowed students to make connections between the science ideas and their personal, cultural, and social experiences. In analyzing the lesson plan, they recognized that students did not have an opportunity to make these connections and thus adapted the lesson to compensate for this weakness. The preservice teachers made a variety of adaptations. Some suggested adding a question that asked students to provide examples of when they have experienced friction in their own lives. Others suggested doing the extension activity with shoes at the end of the lesson or having students write as homework about examples of friction in their homes, as illustrated in Mia’s analysis:
The 'extending the ideas' section could count as this because it talks about different types of shoes. Shoes can look very different in different cultures and places around the world so maybe if they actually did this section; it would tie in kids [sic] personal connections. I think there could be a homework sheet for this experiment that says 'Go home and write down three examples where you see friction working in your house'. This way kids could make a more personal connection. (Mia, Lesson plan analysis assignment 3)

Still others suggested that students write a story about an experience they have had with friction and share their story with the class. Jackie described this modification in her analysis, writing:

There also was not a lot of opportunity in this lesson for students to make connections between the scientific ideas they were generating and their own experiences. A cross curricular activity that might be meaningful for students is to have them write a short story about an experience they had where friction played a role. This would force students to think about why understanding friction is important and they will realize that it is something that they are constantly experiencing. If students were able to share these stories, it would show that in the classroom everyone's experiences are important and valued, making a welcoming environment for all students. (Jackie, Lesson plan analysis assignment 3)

These typical examples show that the preservice teachers tended to understand how to help students connect science ideas with their own personal, social, and cultural experiences.

7c—Making scientific terminology accessible to all students. Only six preservice teachers (6/24) understood how to make scientific terms accessible to all students. In their analysis, they recognized that not all of the students would have the same familiarity with the term 'friction.' As the lesson was written, it introduced the term at the beginning of the lesson and then jumped into an investigation on friction. These preservice teachers modified the lesson to provide students with additional opportunities to think about the meaning of this term before completing the investigation, as illustrated in the following excerpt:

No, I don't believe it does....It may also be helpful for students who are not familiar with the scientific terminology to see an example of the effects of friction, may through a video or a teacher-led experiment before students make their predictions because they will be able to understand friction better. (Jessica, Lesson plan analysis assignment 3)

The rest of the class (18/24) had an alternative understanding of this indicator. They assumed that providing definitions at the beginning of the lesson made scientific terms accessible to all students. Thus, in their analysis, these preservice teachers thought that the lesson plan made the terminology accessible to students by providing them with the definition for ‘friction’ before investigating the science concept. Emily made this assertion in her analysis, writing:

This lesson helps teachers make scientific terminology accessible to all students. At the beginning of the lesson…[the teacher] tells them that friction is ‘a force (or pull) that allows down moving objects.’ In this way, she is making certain scientific terminology available for all students in that she is reciting the definition to the whole class. (Emily, Lesson plan analysis assignment 3)

Most of the preservice teachers thought that students simply needed to hear a definition in order to develop an understanding of a particular science concept. Possessing this alternative understanding may lead teachers to alienate students who may not be familiar with the norms of scientific language, thus impacting students’ ability to experience success in learning science.
Appendix D

Examples of the Alternative Understandings of the Reform-Based Criteria in the Reflective Teaching Assignments

This section builds upon the findings from the lesson plan analysis assignments dealing with preservice teachers’ alternative understandings of the reform-based criteria. Below are examples from their reflective teaching assignments illustrating the indicators with which the preservice teachers tended to struggle, along with descriptions of the alternative understandings underlying those unmet indicators. These descriptions also note which alternative ideas were similar to and different from the alternative ideas that emerged from the lesson plan analysis assignments.¹

Criterion 1—Attending to Learning Goals

1a—Including inquiry and content learning goals. The reflective teaching assignments reminded the preservice teachers to include both content and inquiry learning goals in their lesson plan. The science methods course described inquiry in terms of the practices of questioning and predicting, gathering evidence and using it to develop scientific explanations, and communicating and justifying findings (NRC, 2000). However, many of the preservice teachers (RT1: 13/24; RT2: 16/24) did not include learning goals that emphasized these inquiry practices. For example, Debbie analyzed her learning goals as part of her analysis to determine whether they addressed both content and inquiry and came up with the following goals, writing:

• Students will be able to develop an understanding that science is a human endeavor by reading about what paleontologists study.
• Students will develop an understanding that dinosaurs are like other organisms that are alive today. (Debbie, Reflective teaching assignment 1—revised lesson plan)

Neither of these learning goals actually addressed inquiry. Examining the preservice teachers’ analysis tasks revealed two alternative understandings underlying the misapplication of this indicator. Like in the lesson plan analysis assignments, some of the preservice teachers evaluated the lesson plan, rather than the learning goals, for inquiry. For example, Debbie demonstrated this alternative understanding in her analysis of her lesson plan, writing:

This lesson does address the science content of dinosaurs, but it is lacking to address inquiry. As you will read, I have created a journal page for the students to do to make the lesson more inquiry based; obviously the discussions (and the questions I will ask) we will have (as you will read) will also help to make the lesson inquiry based as well. (Debbie, Reflective teaching assignment 1—lesson plan analysis task)

Here, Debbie analyzed her lesson plan, not its learning goals, to see if it addressed inquiry, leading her to omit inquiry learning goals in her revised lesson plan, as shown above. Failing to articulate inquiry learning goals may result in missed opportunities to hold students accountable for developing particular inquiry understandings and abilities.

Others struggled with including inquiry learning goals because they possessed an alternative understanding of inquiry. For example, Emily, Carmen, and Claire taught the same lesson plan and all three of them decided to keep the same learning goals from the original lesson plan in their revised lesson plan, after applying this indicator in their analysis. They wrote:

Students will be able to:
• Learn and discuss ideas about how clouds are made.
• Become familiar with different cloud types on a chart.
• Make models of the three basic cloud shapes.
(Reflective teaching assignment 1—revised lesson plan)

¹ We were only able to discern the preservice teachers’ alternative understandings of the criteria if they applied the criteria in the lesson plan analysis part of the reflective teaching assignment and demonstrated misapplication of the criteria. Otherwise, we did not have access to the rationales that the preservice teachers used to justify their analyses since only the lesson plan analysis tasks, not the revised lesson plans, provided this additional information. Thus, we were not able to articulate patterns in alternative understandings for criteria that few preservice teachers chose to focus on in their analysis and for criteria that the preservice teachers tended to correctly apply in their analysis.
These preservice teachers stated that the first two learning goals addressed content and the third one addressed inquiry, as illustrated in Emily’s lesson plan analysis:

As far as content is concerned, the learning goal of discussing ideas about how clouds are made and becoming familiar with different cloud types on a chart both involve teaching children about the necessary content. The learning goal of making models of the three basic cloud shapes addresses inquiry because the teacher doesn’t give the class an example of what their picture should look like. Rather, the kids are told what cloud shapes to make and have to make them on their own. (Emily, Reflective teaching assignment 1—lesson plan analysis task)

In this lesson plan students used cotton balls to illustrate different cloud types, but the preservice teachers told the students how to make each cloud type, as shown in Emily’s lesson plan:

I will give them clues on how to form these clouds and also post a chart up of these clues at the front of the room to remind the children while they are working. For cumulus clouds, I will tell them to glue some cotton balls down in the shape of an animal. For cirrus clouds, I will tell them to pull a cotton ball into long threads before gluing it down and for stratus clouds, I will tell them to glue the square or circular cotton pads down. (Emily, Reflective teaching assignment 1—revised lesson plan)

Emily, as well as Carmen and Claire, mistakenly thought that having their students make these cloud models would provide them with the opportunity to engage in inquiry. Possessing an inaccurate understanding of inquiry may result in missed opportunities to engage students in genuine inquiry and thus to develop their inquiry understandings and abilities.

Criterion 2—Establishing a Sense of Purpose

2b—Making the purpose meaningful to students. The majority of the preservice teachers (RT1: 18/24; RT2: 14/24) struggled with helping students see the purpose of the lesson as meaningful and relevant to their lives. For example, Amelia helped students learn about static electricity but did not help them understand how this scientific concept related to the real world, even though she applied this indicator in her analysis (Reflective teaching assignment 1—revised lesson plan). Preservice teachers, like Amelia, who did not help students see the purpose as meaningful tended to demonstrate one main alternative understanding with regard to this indicator. Like in the lesson plan analysis assignments, they evaluated the lesson purpose to see if it would be meaningful to students rather than the lesson plan itself to see if helped students see the purpose as meaningful. Amelia illustrated this alternative understanding in her lesson plan analysis, writing:

The subject of static electricity is meaningful to students because students encounter this phenomena on a daily basis in the forms of shocks from the McDonald’s Playland slides, the wrappers of their juice box straws “sticking” to their hands, and many others. (Amelia, Reflective teaching assignment 1—lesson plan analysis task)

Here, Amelia recognized that the concept of static electricity was potentially meaningful to students but did not provide any opportunities to help students see this during the lesson. Assuming students will see the purpose as relevant to their own lives without explicitly helping them make these connections may result in missed opportunities for students to recognize how scientific ideas are personally meaningful, thus impacting their motivation to learn about science.

Criterion 3—Eliciting Students’ Initial Ideas and Predictions

3a—Eliciting ideas and predictions at start of lesson. Most of the preservice teachers (RT1: 17/24; RT2: 19/24) incorrectly applied this indicator in their analysis. Typically the preservice teachers elicited students’ initial ideas about the new content but not their predictions about the phenomena. This occurred despite the fact that the reflective teaching assignments explicitly reminded the preservice teachers to elicit students’ existing ideas in the introduction of the lesson and help students make predictions during the main part of the lesson. For example, before engaging in the lesson activity, Claire initiated a discussion at the start of the lesson to find out students’ prior ideas about clouds. She wrote:

Connect this lesson to the previous one by reminding students about meteorologists and the way that scientists approach new ideas. Ask, “What do we know about clouds?” as a question to elicit student thinking. Write responses on a piece of chart paper labeled “What we know about clouds.” (Claire, Reflective teaching assignment 1—revised lesson plan)
This was the only time students shared their ideas at the beginning of the lesson. Thus, Claire did not provide students with the opportunity to make predictions about the phenomena.

Similar to the lesson plan analysis assignments, the preservice teachers tended to possess the alternative understanding that eliciting students’ initial ideas about the new content was the same as eliciting their predictions about the phenomena. Claire illustrated this alternative understanding in her application of this indicator in her analysis, writing:

At the beginning of the lesson, does the lesson enable the teacher to elicit students’ ideas about the new content and predictions about the phenomena? This is addressed in the lesson in the first science talk led by the teacher. In this talk, the teacher is recording students’ initial ideas and predictions about clouds. (Claire, Reflective teaching assignment 1 — lesson plan analysis task)

Like her peers, Claire did not differentiate between eliciting students’ initial ideas and eliciting their predictions when she mistakenly asserted that the discussion at the beginning of the lesson would allow her to elicit both initial ideas and predictions. Failing to make a distinction between these two types of ideas may result in missed opportunities to help students learn how to make predictions about the phenomena and thus to learn about an essential aspect of inquiry.

3b—Eliciting explanations for students’ ideas/predictions. The majority of the preservice teachers (RT1: 15/24; RT2: 20/24) struggled with having students provide explanations for their initial ideas about the new content and predictions about the phenomena. For example, Leah elicited students’ ideas about mixtures and other related concepts but failed to elicit their explanations for their ideas, even though she applied this indicator in her analysis. She wrote:

I will connect this lesson to the previous one (regarding atoms and molecules) by conducting a review with the students to get their minds thinking of what they already know. The investigation question for this lesson is “What is a mixture?” I will elicit students existing ideas by asking them what they know about atoms, molecules, compounds, mixtures and elements and helping them generate examples for each of these that they can refer to later in the lesson. (Leah, Reflective teaching assignment 2 — revised lesson)

This typical example shows that many preservice teachers failed to elicit students’ explanations for their initial ideas or predictions, even though more than three-fourths of them applied criterion 3 in their analyses in both reflective teaching assignments.

The most common alternative understanding of this indicator expressed by the preservice teachers was the idea that having students share their ideas out loud would allow them to give explanations. Leah communicated this perspective in her analysis, writing, “Students are able to explain their ideas about the new content to the entire class as we will be reviewing it as a group” (Reflective teaching assignment 2 — lesson plan analysis task). Similarly, Mia also analyzed her lesson plan for opportunities for students to give explanations for their initial ideas and concluded that, “Yes, in the introduction I have the kids share out loud their answers” (Reflective teaching assignment 2 — lesson plan analysis task). These responses suggest that the preservice teachers either assumed that sharing ideas in discussion was the same as providing explanations for ideas or that sharing ideas out loud would necessarily lead students to explain their ideas. Making either of these assumptions may result in missed opportunities to find out the origin of students’ initial ideas and predictions.

**Criterion 4—Providing Experiences with Phenomena**

4a—Providing multiple experiences with phenomena. The majority of the preservice teachers (17/24) provided students with only one experience with the phenomenon. For example, Leah had her students observe differences in evaporation from eight containers with varying surface areas in order to help them see how surface area affects the evaporation of liquids. Similarly, Mia provided her students with only one way to learn about rivers in her lesson, writing, “We are going to use resources from the book, and on the internet, to find out different facts and characteristics about the [Mississippi] river” (Reflective teaching assignment 2 — revised lesson plan). These typical examples show that most of the preservice teachers did not allow students to experience a range of phenomena, thus limiting the opportunities they had to learn about scientific ideas.

Some preservice teachers may have had to negotiate time constraints for their lesson, leading them to provide students with only one experience with phenomena. However, the preservice teachers who applied this criterion in their analysis expressed one main alternative understanding. These preservice teachers thought they
provided students with multiple experiences with phenomena if they enabled their class to experience the concept through different senses. Leah illustrated this alternative understanding in her analysis, writing:

I chose to use this [criterion] in my analysis because since so many of my students have special needs, they learn best by hearing, seeing, and experimenting with new/old information. The information will be written on the overhead, myself and the students will verbally say it, and we will test it with our experiment. (Leah, Reflective teaching assignment 1—lesson plan analysis task)

Leah, along with many of her classmates, did not understand what counted as an experience with scientific phenomenon. Failing to understand this idea may limit the opportunities that students have to experience phenomena, and in turn, recognize the explanatory power of science ideas.

**Criterion 5—Promoting Sense Making**

5a—Having students develop evidence-based explanations. Three-quarters of the preservice teachers (18/24) struggled with having students develop evidence-based explanations. Typically, the preservice teachers had students answer a few questions related to the science content but did not ask them to provide evidence from the lesson to support their claims. Others asked their students to simply share one thing they had learned from the lesson. For example, Carmen ended her lesson on rain in the following way, writing:

I will discover whether or not students have taken anything from this lesson about rainfall by asking students to volunteer ideas about what they have learned. My students will construct explanations about what they have learned by I will ask [sic] students, “What have you learned today? Can you tell me one thing?” I will call on several volunteers to explain their answer to the rest of the class. (Carmen, Reflective teaching assignment 2—revised lesson plan)

This typical example shows that the preservice teachers tended to misapply or not address this indicator, resulting in missed opportunities for students to develop evidence-based explanations.

Some preservice teachers undoubtedly failed to address this indicator because they did not apply the indicator in their analysis. However, others did not address the indicator because they possessed an alternative understanding of a scientific explanation. Some preservice teachers defined an explanation as any statement that provided reasons or details for something. Leslie demonstrated this understanding in her revised lesson, writing:

After watching the video clip, have students individually complete the evaluation section on the worksheet. As a class develop a list of elements every students should include in their revised scientific model. Give students 10 minutes to draw a new diagram [about how lightning forms] and write an explanation of their model. Walk around and remind students to include all of the elements on the class list and encourage them to be detailed in their diagram and explanation. Students can share with a partner when finished. (Leslie, Reflective teaching assignment 2—revised lesson plan)

Others, like Carmen above, conceptualized an explanation even more broadly, defining it as any response to a question where students have the opportunity to share their ideas. In this instance, having students ‘tell,’ ‘describe,’ or ‘explain’ what they think are all viewed as synonymous terms. Both of these alternative understandings of a scientific explanation have one thing in common—a de-emphasis on the role of evidence. Failing to hold students accountable for providing evidence for their ideas may result in missed opportunities for students to learn how to support their ideas and make connections between scientific concepts and their explorations.

**Criterion 6—Assessing Student Learning**

6a—Assessing content understanding and inquiry abilities. Two-thirds of the preservice teachers (16/24) simply listed the assessments they would use without showing how they were aligned with the learning goals. For example, Kimberly planned on using a worksheet and other assessments to gauge student learning about instincts and learned behaviors but did not articulate the connections between the assessments and the content understandings and inquiry abilities they were intended to measure. She wrote:

I will be collecting the hand-out after it has been filled in by each of the students to give me a formal understanding of what they learned. I will also be looking for informal assessments throughout the lesson to see who participates and when. (Kimberly, Reflective teaching assignment 2—revised lesson plan)

Like in the lesson plan analysis assignments, these preservice teachers assumed that having an assessment would automatically allow them to measure student learning with regard to their learning goals. Making this assumption
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may result in missed opportunities to assess particular ideas and abilities and thus opportunities to provide feedback and revision for students.

6c—Asking students to apply their ideas to a new task. Three-quarters of the preservice teachers (18/24) did not have students apply their ideas to a new situation or task. However, most of them asserted in their revised lesson plans that they provided students with this opportunity. The preservice teachers tended to misapply this indicator because they possessed an alternative understanding of it. They thought students applied their ideas to a new situation or task if they used what they had learned from a reading or experiment to complete a worksheet or an assessment directly connected to the reading or experiment. Debbie illustrated this alternative understanding in the following excerpt, writing, “The properties the students observed would help them apply their newly acquired knowledge on liquids to their journal pages/grids about the bottles of liquids they had just investigated” (Reflective teaching assignment 2—revised lesson plan). Similarly, Kelly thought students had the opportunity to apply their ideas to a new task by completing a worksheet following a whole class discussion, even though the worksheet and discussion related to the same situation. She wrote, “These assessments are very grounded in the key content, and students will have to apply the ideas of our discussion in order to complete their worksheet” (Reflective teaching assignment 2—revised lesson plan). These examples show that many preservice teachers did not give students a new task or situation in which to apply their new knowledge. This alternative understanding may result in missed opportunities for them to see if students can extend their ideas beyond the specific situation in which they were introduced.

Criterion 7—Making Science Accessible for All Students

7a—Attending to the needs of individual students. The majority of the preservice teachers (17/24) did not individualize their lesson plan at all. They did not take into consideration how the lesson might need to be adapted for specific students or groups of students. The two preservice teachers who applied this indicator in their analysis of their lesson plan shed light on one alternative understanding underlying this indicator. Like in the lesson plan analysis assignments, these preservice teachers thought this indicator was met if the teacher had the opportunity to circulate among students during group work or independent work because this would allow them to interact with students one-on-one. For example, Lisa asserted that her lesson met this indicator, writing, “During the whole class modeling, I can circulate the room and address the needs of individuals while talking with the whole class at the same time” (Reflective teaching assignment 2—lesson plan analysis task). Similarly, Carmen thought the needs of individual students would be met if the teacher merely circulated around the classroom:

I do not think that this particular lesson is the best example of helping a teacher to attend to the needs of individual students in my classroom. This is because the teacher does not have any time during which the students are working independently and they have the ability to walk around the classroom and have short conversations with each student. (Carmen, Reflective teaching assignment 2—lesson plan analysis task)

These preservice teachers analyzed their lesson plans to see if they had the opportunity to help students, in general. Interpreting the indicator in this way may result in missed opportunities to differentiate instruction for specific students or groups of students in their classroom.

7c—Making scientific terminology accessible to all students. Roughly half of the preservice teachers (13/24) did not meet this indicator. Some included unnecessary terminology that was not connected to their learning goals. Others provided students with a list of terms and definitions at the beginning of their lesson and then engaged them in experiences to validate these definitions, rather than having them develop their understanding of the terms by building from their own ideas and experiences. For example, Kelly introduced her lesson by providing students with a list of liquid properties (e.g., viscosity, translucent, transparent) and their definitions and then had students investigate the different properties. Her lesson read:

This lesson is intended to teach students the properties of liquid...The vocabulary words are discussed as a class and further shown on the property posters. Students work in groups to look closely at the liquids and decide whether or not they hold each of the properties. When they are finished, students may play liquid vocabulary card games to practice the new words. (Kelly, Reflective teaching assignment 2)

Preservice teachers, like Kelly, assumed that providing definitions at the beginning of the lesson would make scientific terms accessible to all students. This alternative understanding also emerged in the lesson plan analysis assignments. Assuming students learn science simply by memorizing definitions may result in missed opportunities for students to make sense of science for themselves and thus to develop a deep understanding of scientific concepts.