

Preservice Elementary Teachers' Adaptation of Science Curriculum Materials for Inquiry-Based Elementary Science

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ABSTRACT: Curriculum materials are important resources with which teachers make pedagogical decisions about the design of science learning environments. To become well-started beginning elementary teachers capable of engaging their students in inquiry-based science, preservice elementary teachers need to learn to use science curriculum materials effectively. Thus far, few other studies have investigated how preservice elementary teachers adapt science curriculum materials to better reflect five essential features of inquiry-based teaching and learning articulated in contemporary science education reform. Findings from previous research suggest that preservice elementary teachers can productively adapt science curriculum materials to make them more inquiry-based. The mixed-methods study presented here extends these findings by illustrating the essential features of inquiry preservice teachers emphasize in their curricular adaptations and the specific types of adaptations the preservice teachers make. Results suggest that the preservice teachers consistently attended to all five essential features of inquiry in their curricular adaptations. The types of

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adaptations that they made to promote each of these features of inquiry provide insight into their curriculum design practices and learning about science as inquiry that can serve as important leverage points for teacher education experiences and curriculum materials designed to support elementary teachers' science teaching practice and learning. © 2011 Wiley Periodicals, Inc. *Sci Ed* 95:927–955, 2011

INTRODUCTION

A core mission of formal science teacher education is to support preservice teachers' learning to engage students in science as inquiry in the classroom. To fulfill this mission, teacher educators must confront and overcome numerous challenges, including a lack of knowledge preservice teachers typically possess about effective science teaching (Abell, 2007; Bryan & Abell, 1999; Davis, Petish, & Smithey, 2006; Zembal-Saul, Blumenfeld, & Krajcik, 2000), the programmatic limitations of traditional teacher education models (e.g., Ball & Forzani, 2009), and institutional school cultures that have repeatedly been shown to support the status quo rather than reform-minded, standards-based, inquiry-oriented science teaching and learning (e.g., Grandy & Duschl, 2007). Current norms of elementary school culture, including a de-emphasis on science in the curriculum (Marx & Harris, 2006; Spillane, Diamond, Walker, Halverson, & Jita, 2001) and the misrepresentation of science "activities that work" (Appleton, 2002) as effective, inquiry-based learning opportunities, can have a particularly powerful influence on preservice elementary teachers' development as teachers of science.

To ensure that preservice elementary teachers learn to confront these challenges and become tomorrow's well-started beginning elementary teachers (Avraamidou & Zembal-Saul, 2010), teacher education programs should foreground engaging preservice teachers in authentic teaching practices and the analysis of practice (e.g., Ball & Forzani, 2009; Grossman, McDonald, Hammerness, & Ronfeldt, 2008). These practice-based perspectives on teacher education, which are aligned with situated and activity-based perspectives on teacher learning and expertise (Forbes, Madeira, & Slotta, 2010; Putnam & Borko, 2000), are enjoying a subtle resurgence as a means to fundamentally reform teacher education, address the well-documented disconnect between teacher education and the classroom that many preservice teachers articulate, and to respond to growing pressure from policymakers. Such programs, which often involve synergistic alignment of postsecondary programmatic elements and K-12 contexts, can support preservice teachers to successfully transition from novice to effective science teachers (Zembal-Saul et al., 2000).

Elementary science teacher educators have begun to emphasize engaging preservice teachers in the evaluation and use of science curriculum materials as one means to more explicitly emphasize preservice teachers' analysis and engagement in science teaching practice (Beyer & Davis, 2009a; Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008). This research has made important contributions to the field's collective understanding of how preservice elementary teachers learn to plan with and enact science curriculum materials, as well as how curriculum materials and curriculum-focused teacher education experiences can be designed to promote preservice teachers' learning. More research is needed to investigate how preservice teachers engage in these curriculum design processes to promote and scaffold students' participation in the epistemic practices of science. The study presented here contributes to this body of research by focusing on how preservice teachers adapt science curriculum materials to improve students' opportunities to engage in essential features of classroom inquiry as

defined in contemporary science education reform (National Research Council [NRC], 2000).

Theoretical Perspectives on the Teacher–Curriculum Relationship

This research is grounded in contemporary perspectives on the teacher–curriculum relationship that emphasize the active, participatory interactions by which curriculum materials are translated into classroom activity (Brown, 2009; Remillard, 2005). Curriculum materials have long been viewed as a primary means through which to infuse the methods and goals of educational reform into the science classroom. Historically, for their part, teachers were often considered passive enactors of these curriculum materials. Most curricular resources developed over the years were designed to speak *through* teachers rather than directly *to* them (Remillard, 2000). Teachers rarely enact curriculum materials precisely as written. Contemporary perspectives on the teacher–curriculum relationship have recognized and are beginning to embrace as an affordance the important role teachers play in curriculum materials use.

For teachers, curriculum materials serve as both tools—in that they mediate teachers' professional practice—and artifacts—in that they are material products of teachers' professional practice. The interactive relationship between teachers and curriculum materials occurs across two crucial domains of professional practice—*curriculum planning*, or the design area, and *curriculum enactment*, or the construction arena (Remillard, 1999). In curriculum planning, teachers mobilize and leverage their personal resources (Brown, 2009), or professional toolkits composed of symbolic tools (i.e., knowledge, beliefs, identities, and orientations) and material tools, such as curriculum materials, to instantiate imagined classroom practice in curriculum-based procedures and plans. Curriculum enactment is embodied by a core triadic relationship between the teacher, students, and curriculum in which teachers mobilize these curriculum materials as tools to engage students in classroom learning activities (Cohen & Ball, 1999). Ultimately, teachers' learning and expertise is an emergent property of iterative cycles of curriculum planning and enactment over time.

Teachers' use of curriculum materials can be viewed as a three-part curriculum design process instantiated in contemporary models of the teacher–curriculum relationship across the science and mathematics education research communities (Brown, 2009; Forbes & Davis, 2010a; Remillard, 2005). First, teachers mobilize curriculum materials to varying degrees dependent upon what curricular resources are available to them. Second, their use of these curriculum materials can be characterized along a continuum from implementation with absolute fidelity, in which teachers enact curriculum materials as designed, to *invention* (Remillard, 1999) or *adaptation* and *improvisation* (Brown, 2009), in which curriculum materials serve as a foundation for modification based upon their professional decision making. Third, these curriculum design practices have explicit outcomes for both planned and enacted instruction. Ultimately, curriculum design processes and outcomes in science are a function of science teachers' personal resources (knowledge, beliefs, orientations, and identities), features of the curriculum materials they use, and affordances and constraints of their professional contexts (Brown, 2009; Enyedy & Goldberg, 2004; Pintó, 2004; Roehrig & Kruse, 2005; Roehrig, Kruse, & Kern, 2007; Schneider, Krajcik, & Blumenfeld, 2005). The focus of this study is on patterns in preservice elementary teachers' adaptation of science curriculum materials specifically to promote inquiry-based teaching and learning.

Research on Teachers' Adaptation of Science Curriculum Materials

Curriculum materials are crucial resources for elementary teachers across subject areas (Avraamidou & Zembal-Saul, 2010; Forbes and Davis, 2010b; Kauffman, Johnson, Kardos, Liu, and Peske, 2002; Remillard, 2000; Valencia, Place, Martin & Grossman, 2006). However, while some past research has focused on elementary teachers' use of curriculum materials for mathematics and language arts, there is little similar research that has investigated their use of similar resources for science, especially prevalent reform-oriented, kit-based elementary science curriculum materials. Findings from studies investigating middle and secondary teachers' use of science curriculum materials have shown that the quality of science teachers' curricular adaptations can vary (e.g., Enyedy & Goldberg, 2004; Fogleman, McNeill, & Krajcik, 2010; Pintó, 2004; Roehrig & Kruse, 2005; Roehrig et al., 2007; Schneider et al., 2005; Squire, MaKinster, Barnett, Luelmann, & Barab, 2003). Such localized curricular adaptations may well reflect teachers' local, context-rich knowledge and therefore best reflect the needs of particular students within specific settings. In particular, teachers may adapt curriculum materials to more productively engage and motivate their students (Squire et al., 2003) or directly involve them in inquiry-based investigations rather than vicarious experiences (Fogleman et al., 2010). Other adaptations may be benign or neutral, having little if any overall impact on measurable outcomes. On the other hand, teachers may make changes to curriculum materials and/or enact them in ways that are less effective. Teachers' adaptations can "demote" the goals of curriculum developers (Pintó, 2004) and not all adaptations made by teachers are consistent with students' science learning needs (Schneider et al., 2005).

These studies illustrate the wide-ranging effects of teachers' adaptation of science curriculum materials. While teachers' curricular adaptations are often minor and inconsequential, they can also fundamentally shape the formation and maintenance of core classroom cultures defined by discourse patterns and the distribution of roles and authority (Enyedy & Goldberg, 2004; Squire et al., 2003). There is also growing evidence of essential relationships between teachers' curricular adaptations and students' science learning (Fogleman et al., 2010). As such, it is crucial that teachers learn to adapt curriculum materials productively through coherent mobilization and alignment of their personal characteristics (knowledge, beliefs, identities, and orientations) and affordances and constraints of their professional contexts (Brown, 2009). To characterize teachers' learning and expertise, it is necessary to understand how they learn to use curriculum materials to plan instruction as well as how they use these instructional plans to engage students in the classroom.

Foregrounding Teacher–Curriculum Interactions in Teacher Education

Past research has shown that preservice elementary teachers often struggle to translate their ideas into inquiry-based classroom science teaching (Bryan & Abell, 1999; Crawford, 1999, 2007; Forbes & Davis, 2008; Zembal-Saul et al., 2000) and tend to rely heavily on curriculum materials as beginning elementary teachers (Forbes & Davis, 2010b, 2010c; Avraamidou & Zembal-Saul, 2010; Kauffman et al., 2002; Valencia et al., 2006). As such, it is particularly important for preservice elementary teachers to learn how to use and adapt curriculum materials to engage students in science as inquiry as part of their formal teacher education. University-based teacher education experiences can be designed to afford preservice teachers opportunities to deconstruct and critically analyze specific components of science teaching practice that elementary classrooms often do not (Sim, 2006; Zembal-Saul et al., 2000).

As representations of science teaching practice, particularly those iteratively developed and refined over time by teachers in particular settings, curriculum materials can serve as functional, interpretable representations of teachers' expertise (Ball & Lampert, 1999; Loughran, Mulhall, & Berry, 2004). They are particularly important for preservice teachers in that they can provide them with opportunities to situate communication about science teaching and learning in common contexts at a point along the teacher professional continuum (Feiman-Nemser, 2001) when their classroom experience is limited. Curriculum-focused teacher education experiences can also be designed around curriculum-based models of teacher professional communities, which have been shown to be effective in supporting teachers' curriculum planning and enactment in professional development contexts (e.g., Fishman, Marx, Best, & Tal, 2003). Working critically with curriculum materials over time, particularly in collaboration with colleagues, is a means through which to support teachers to make their developing expertise explicit and support their learning about inquiry-based elementary science over time.

To support preservice elementary teachers' learning to teach reform-minded, inquiry-based science, elementary science teacher educators have designed and studied elementary science teaching methods courses that foreground teacher–curriculum interactions (Beyer & Davis, 2009a; Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008). Findings from these studies provide some insight into how preservice elementary teachers interact with and implement science curriculum materials. Preservice elementary teachers possess an existing set of criteria by which they critique science curriculum materials, although their ideas are not always aligned with those advocated by science educators, and they may not attend to critical elements of inquiry-based science teaching and learning. However, they can learn to appropriate and use reform-based criteria in their evaluation of curriculum materials, particularly when there is alignment between these constructs and their own goals and priorities. Preservice teachers can also construct a professional identity in which the active, participatory use of curriculum materials is a central element. Finally, these studies have provided evidence that lesson-specific educative elements of science curriculum materials can provide preservice elementary teachers with productive contexts for reflection on science teaching practice when opportunities to actually engage in science teaching are limited.

STUDY OVERVIEW AND RATIONALE

The body of research focused on preservice elementary teachers' use of science curriculum materials has made important contributions to the knowledge base in science education (Beyer & Davis, 2009a; Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008). These studies have largely emphasized preservice elementary teachers' *critique* and *evaluation* of existing science curriculum materials rather than how they actually *adapt* them. The findings presented here are part of a larger study that addresses this gap in existing research by investigating how preservice elementary teachers actually *adapt* science curriculum materials to promote students' engagement in inquiry practices.

In this study, I draw explicitly upon the five essential features of inquiry articulated by the National Research Council in the *National Science Education Standards* and other associated documents (NRC, 1996, 2000, 2007) as a comprehensive conceptual and analytical framework used across both the instructional (science methods course) and empirical components of this research. These five essential features of inquiry include the following:

1. Engaging in scientifically oriented questions
2. Gathering, organizing, and analyzing data
3. Formulating explanations from evidence to address scientifically oriented questions
4. Evaluating explanations in light of alternative explanations
5. Communicating and justifying explanations

Each of these five essential features can be evident in more teacher-directed or student-directed forms of inquiry, with neither being more inquiry based than the other, as required by students' needs for explicit instructional and curricular scaffolding (NRC, 2000). The foregrounding of the five essential features of inquiry is an important aspect of this study since few other studies have similarly drawn upon this framework, emphasized in systemic science education reform, to undertake research on teachers, teachers' practice, and teacher learning (Davis et al., 2006).

Previous findings have shown that preservice elementary teachers can adapt existing science curriculum materials to make them more inquiry-based, although this predominantly remains a function of how inquiry-based the curriculum materials are to begin with (Forbes & Davis, 2010a). In the study presented here, I ask the following research questions to further explore preservice elementary teachers' adaptation of science curriculum materials:

1. Are preservice elementary teachers able to adapt science curriculum materials to better promote students' engagement in each of the five essential features of inquiry?
2. What types of adaptations do preservice elementary teachers make to existing science curriculum materials to promote students' engagement in these five essential features of inquiry?

This study extends previously published findings in two ways. First, rather than focusing on aggregate inquiry scores as an outcome measure of the preservice teachers' curricular adaptations, I investigate whether preservice elementary teachers are able to adapt existing science curriculum materials to better provide opportunities for students to engage in *each of the five essential features of inquiry* (NRC, 2000). Second, I explore *how they adapt* science curriculum materials by investigating the types of modifications they make to promote students' engagement in these five essential features of inquiry. Findings from this study contribute not only to a body of research focused on preservice elementary teachers' use of science curriculum materials (Beyer & Davis, 2009a; Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008) but also more broadly to teacher-curriculum research across science and mathematics education research communities (Brown, 2009; Remillard, 2005).

METHOD

This nested, mixed-methods (Yin, 2009) study involved preservice elementary teachers in an undergraduate elementary science teaching methods course and is composed of two components. First, artifacts associated with two science lessons planned and taught by all preservice teachers ($n = 46$) were analyzed to investigate which of the five essential features of inquiry they emphasized in their curriculum adaptations. Second, six of these preservice teachers were studied as cases over the course of the semester to better understand how they adapted their lessons to better engage students in the five essential features of inquiry.

Participants and Context

This study took place during the third semester of an undergraduate elementary teacher preparation program at a large, Midwestern university in the United States. During the third semester, preservice teachers are enrolled in the elementary science teaching methods course designed around two goals for preservice teacher learning: inquiry-oriented science teaching and learning and the use of science curriculum materials (see Davis & Smithey, 2009, for a description of the course and its foundations). The five essential features of inquiry were used as a comprehensive framework in the course for the evaluation and design of effective science instruction. Preservice teachers were first introduced to these five essential features of inquiry in the second week of the course. Throughout the semester, they learned to use the five essential features framework as an evaluative and design tool to complete a variety of course activities and assignments, such as lesson plan critiques, video analyses, and the construction and negotiation of models of science teaching and learning. Through these activities, they constructed sets of specific instructional strategies aligned with each of the five essential features. The purpose of this process was to help them develop a more usable understanding of specific methods through which to promote students' engagement in these essential features of inquiry.

During the methods semester, the preservice teachers were asked to plan, develop, teach, and reflect upon two elementary science lessons. These assignments were called reflective teaching assignments (RTs; see Davis & Smithey, 2009) and were the two most substantial assignments in the elementary science methods course. The RT assignments (RT1 and RT2) capitalized on the preservice teachers' semester-long field placements (6–8 hours per week) in local elementary classrooms. RT1 occurred approximately halfway through the semester after the preservice teachers had been introduced to and worked with the five essential features of inquiry framework for approximately 8 weeks. RT2 occurred approximately 1 month after RT1. Because of their relatively close proximity to one another, the RT assignments are not intended to provide a measure of change over time for either instructional purposes or empirical research. Rather, the purpose of the RT assignments was to afford the preservice teachers two similar opportunities to implement their ideas and strategies in authentic elementary classroom settings and, in doing so, gain experience planning, enacting, and reflecting upon inquiry-oriented science teaching using a variety of science curriculum materials.

For each of the reflective teaching assignments, the preservice teachers were asked to first critique and then adapt an existing science lesson or set of science curriculum materials to produce a more inquiry-based, revised science lesson. The instructional goals and curricular topics in their placement classrooms largely determined what curriculum materials they had to work with. The preservice teachers were not given specific direction about which existing science lessons to use. Most used science lessons and associated materials from the science curriculum materials in their placement classrooms, which were primarily kit-based resources from major commercial publishers. Some instead mobilized science lessons from other sources, such as other kit-based elementary science curricula and online sources. Time was allotted in the methods class for collaborative lesson planning and feedback from peers and the course instructors, although the preservice teachers planned their lessons primarily outside of class at their own pace and in collaboration with their cooperating teachers. The preservice teachers enacted their lessons in their placement classrooms and wrote scaffolded postenactment reflective journals that were submitted as part of their RT assignments.

In the semester during which this research took place, I was the instructor for one section of the course, whereas the other section was taught by a colleague. The other instructor and I coplanned the course. It was intentionally designed to be consistent across sections.

TABLE 1
Grade Level, RT Lesson Topics, and Change in RT Lesson Inquiry Scores for Six Case Study Preservice Teachers

	Grade	RT1 Topic	RT2 Topic	RT1		RT2	
				Δ score	% Δ	Δ score	% Δ
Kelly	4	Decomposers	Fungi Growth	0.8 (0.2)	400	0.8 (1.6)	50
Mike	3	Habitats	Variation	1.0 (0.6)	166	0.8 (1.6)	50
Aliza	4	Plant Growth	Plant Growth	0.6 (1.8)	33	0 (3.0)	0
Lauren	3	Habitats	Moon	0.6 (0.4)	150	0 (0.6)	0
Kim	4	Plant Growth	Food Web	1.0 (1.2)	83	0.8 (0.6)	133
Alex	5	Force and Motion	Energy Transfer	0.2 (2.8)	7	0.8 (0.6)	133

Original aggregate inquiry scores for the preservice teachers’ original lesson plans appear in parentheses after the change in inquiry scores between their original and revised lesson plans.

Between the two sections, there were 46 preservice elementary teachers who agreed to participate in this research ($n_1 = 22, n_2 = 24$). All were traditional fourth-year seniors (about 21 years old) in their final year of college and representative of the population of elementary teachers in the United States in that most were female and Caucasian (National Center for Education Statistics, 2003).

From these 46 preservice teachers, seven from the section of the course taught by the author were identified and invited to participate in in-depth case studies centered around their science teaching during the methods semester. These preservice teachers were selected from the methods course using a combination of typical-case and maximum-variation sampling (Patton, 2001). The purpose of this sampling was to select preservice teachers who represented the highest variation in elementary school placements, particularly the types of science curriculum materials being used and topics being taught, while still being representative of the larger group of preservice teachers. During the semester, one of the seven preservice teachers was asked to decommit due to course performance. The data for the case studies are therefore drawn from six preservice elementary teachers—Kelly, Mike, Aliza, Lauren, Kim, and Alex—followed over the course of the semester in which they were in the elementary science teaching methods course. Information for each of these six preservice teachers is included in Table 1.

Data Sources and Collection

This study is based on a data collected during the methods semester from 46 preservice teachers, including six case study teachers. A description of data sources is presented in Table 2.

Reflective teaching assignments and associated artifacts were collected from all 46 preservice teachers in the two sections of the course. The additional interviews, observational data, and small-group discussions were collected only for the six case study preservice teachers.

Data Coding and Analysis

The purpose of data analysis was to characterize the preservice elementary teachers’ adaptation of science curriculum materials for each of the five essential features of inquiry.

TABLE 2
Description of Data Sources

Data Source		Description	Purpose
Artifacts	Reflective teaching assignments	Lesson plans, curriculum materials, reflections, and associated artifacts used in the RT assignments (2 each)	To assess how preservice teachers modify existing curriculum materials to develop science lessons
	Other artifacts from methods course	Additional artifacts, such as online discussion threads, journal entries, and other course assignments collected during the methods semester	Provide additional data, where relevant, to inform description of preservice teachers' use of science curriculum materials over time
Interviews	Formal interviews	Formal interviews emphasizing preservice teachers' learning about inquiry-oriented science teaching (2 each)	Administered at the beginning and end of each semester to assess preservice teachers' ideas about and orientations toward inquiry-oriented science teaching and science curriculum materials
	Pre- and postenactment interviews	Interviews focused around pre- and postenactment planning of RT science lessons and emphasizing planning decisions and rationales for those decisions (2 each)	Before and after each enacted RT lesson to link curriculum design decisions to their underlying rationales
Observational data	Observations of preservice teachers' enacted RT science lessons (2 lessons each)	Characterize and assess preservice teachers' enactment of science lessons, including degree of similarity between planned and enacted lessons	
Planning discussions	Audiorecorded collaborative instructional planning with peers during the methods course	Before and after each enacted RT assignment science lesson during the methods course. Data to illustrate how preservice teachers articulate and justify curriculum design decisions	

To address Research Question #1, I carried out quantitative analyses of artifacts associated with all 46 preservice teachers’ RT1 and RT2 assignments. To address Research Question #2, I engaged in cross-case analyses of the six case studies using all data sources listed in Table 1.

Data Coding. I employed two coding keys to code the data collected in this study. First, I identified the adaptations the preservice teachers made in each lesson using the coding key in Table 3.

These codes are focused on characterizing the *nature* of the preservice teachers’ adaptations and are based on similar coding approaches used by other curriculum researchers

TABLE 3
Coding Key for Adaptations to Curriculum Materials

Types of Changes	Description	Example
Insertions (Ins)	Adds a new element to the lesson plan	Inserts an additional whole-class discussion during the data collection component of the lesson plan
Deletions (Del)	Deletes an element of the existing lesson plan	Removes a teacher-led demonstration in the lesson plan
Substitutions (Sub)	Substitutes a new element for an existing element of a lesson plan	Substitutes a KWL-based whole-class discussion for a teacher presentation in the existing lesson plan
Duplications (Dup)	Includes an existing element from the lesson plan in another part of the lesson plan	Existing lesson plan provides students an opportunity to explicate and provide evidence for their existing explanations as a postinvestigation activity. Teacher adapts lesson to duplicate this opportunity in the beginning of the lesson.
Inversions (Inv)	Switches the order or placement of two or more existing elements of a lesson plan	Existing lesson provides an opportunity for student groups to identify patterns in their data from an investigation (within their small groups) and share their findings with the whole class. Teacher adapts lesson to invert these two lesson components so that students share findings first and discuss patterns second.
Relocations (Rel)	Moves an existing element in the lesson plan to different location in lesson	Existing lesson plan provides an opportunity for students to construct models of phenomena after an investigation. Teacher adapts lesson to relocate the model construction element to occur before students perform the investigation.

(e.g., Drake & Sherin, 2006). These descriptive codes afforded a categorization scheme that also allowed me to identify and quantify instances of the various types of adaptations made the preservice teachers.

Second, I categorized the inquiry practices targeted by each of the preservice teachers' adaptations using the inquiry scoring rubric presented in the Appendix. This coding framework is informed by existing instruments in the field but was developed and piloted in my previous research (Forbes & Davis, 2010a). The inquiry scoring rubric is grounded in the five essential features of inquiry articulated in Inquiry and the National Science Education Standards and elsewhere (NRC, 1996, 2000). Not all coded adaptations were given codes from the inquiry scoring rubric because the preservice teachers made some curricular adaptations that were not specifically intended to promote students' engagement in the five essential features of inquiry. However, by coding each initial and revised lesson plan with the inquiry scoring rubric, I was able to attribute inquiry scores for each of these five essential features of inquiry, as well as composite inquiry scores for each lesson. These two coding keys, then, allowed me to characterize (a) the types and frequencies of adaptations that the preservice teachers made to the curriculum materials they used in their RT lessons, (b) the inquiry practices they sought to target through these adaptations, and (c) inquiry subscores for each of the five essential features of inquiry, as well as an aggregate inquiry score, for their initial and revised RT science lesson plans.

Data Analysis. For inquiry subscores on each of the two RT lessons planned by the 46 preservice teachers in the elementary methods course, I performed interrater reliability with a colleague on a 20% sample of the data (18 lessons). Prior to discussion, coders achieved 86% agreement on inquiry subscores. 100% agreement was reached after discussion. After performing interrater reliability, these data were imported into SPSS for statistical analysis. Paired samples *t*-tests were performed for each inquiry subscore in each of the two RT assignments to compare the effectiveness of the preservice teachers' initial lesson plans and their revised lesson plans. I also compared the changes in scores between the first and second RTs. The primary objective of these analyses was to ascertain which essential features of inquiry the preservice teachers emphasized in their curriculum adaptation (RQ #1). *t*-Test statistics reported in the Results section include Cohen's *d* (*d*) measures of effect size.

Qualitative analytical methods (Miles & Huberman, 1994) were employed to construct case studies (Yin, 2009) for each of the six preservice teachers studied in-depth and to generate cross-case findings for their curricular adaptations in relation to the five inquiry practices (RQ #2). As reported in a previous study (Forbes & Davis, 2010a), in only three of 93 RT lessons analyzed in this study did the preservice teachers' curricular adaptations lower the aggregate, composite inquiry scores of their lesson plans. As such, the vast majority of the preservice teachers' curricular adaptations were either neutral or productive in terms of better instantiating the five essential features of inquiry in their revised lesson plans. The objective of this multiple-case study research, then, was to determine what types of curricular adaptations the preservice teachers made to better engage their students in the five essential features of inquiry.

As noted before, all data for these six case study preservice teachers were coded using coding keys to identify the adaptations they made and which inquiry practices they targeted with these adaptations. Coding queries were first performed on the coded data to identify instances where codes for adaptations (Table 3) and the preservice teachers' ideas about the five essential features of inquiry (Appendix) overlapped. I used the results of these coding queries to construct coding reports for each of the six preservice teachers' RT lessons

that summarized their adaptations and rationales for making them. The preservice teachers were asked to member-check the coding reports for their RT lessons. Following member-checking, I performed cross-case syntheses (Yin, 2009) to identify variation in curricular adaptations the preservice teachers made for each of the five essential features of inquiry. Cross-case themes were tested and retested in light of iterative cycles of data analysis until well-supported, defensible claims were refined and substantiated. In the Results section that follows, quotes from the preservice teachers are labeled name [pseudonym], [data source], [line number(s) from document].

RESULTS

Findings from this study are twofold. First, statistically significant increases in the inquiry subscores for each of the five essential features of inquiry in both of the preservice teachers’ RT lessons provide evidence that the preservice teachers attended to each of the essential features of inquiry in their curricular adaptations. Second, findings from the case studies illustrate the specific ways in which the preservice teachers adapted the science curriculum materials they used to improve students’ opportunities to engage in each of these five essential features of inquiry. In the following sections, I address each research question around which this study was framed.

Inquiry Practices Emphasized in Preservice Teachers’ Adaptations

In Research Question 1, I asked, Are preservice elementary teachers able to adapt science curriculum materials to better promote students’ engagement in each of the five essential features of inquiry? Findings from the preservice teachers’ RT lessons suggest that they were able to increase the inquiry subscores of their lessons for each of the five essential features of inquiry. As shown in Table 4, differences between pre- and postadaptation inquiry scores in both reflective teaching assignments were statistically significant for each of the five essential features of inquiry.

TABLE 4
Differences Between Pre- and Postadaptation Inquiry Subscores
in Preservice Teachers’ RT Lessons

	RT1				RT2			
	\bar{x}	t	df	d	\bar{x}	t	df	d
Questioning	0.57 (0.66)	−5.24***	44	0.89	0.93 (1.02)	−4.46***	45	0.74
Evidence	0.17 (0.19)	−3.71***	44	0.69	0.33 (0.28)	−2.43*	45	0.51
Constructing explanations	0.44 (0.43)	−4.06***	44	0.74	0.56 (0.42)	−5.06***	45	0.85
Comparing explanations	0.48 (0.49)	−4.81***	44	0.79	0.64 (0.52)	−4.70***	45	0.81
Communicating explanations	0.70 (0.61)	−4.13***	44	0.75	0.60 (0.82)	−5.45***	45	0.91

* $p < .01$, *** $p < .001$.
Standard deviations appear in parentheses after means.

These results indicate that through their curriculum adaptations, the preservice teachers were able to improve the inquiry-orientations of their lessons not only in the aggregate but also for each of these five constituent inquiry practices. Across the 93 RT1 and RT2 lessons analyzed, there were only four instances in which the preservice teachers' adaptations resulted in lower inquiry scores for *any* of the five essential features of inquiry. These two sets of findings from the preservice teachers' RT assignments suggest they were effective at improving students' opportunities to engage in all five essential features of inquiry in their planned science lessons.

Types of and Rationales for Curricular Adaptations Made by Preservice Elementary Teachers

In Research Question 2, I asked, What types of adaptations do preservice elementary teachers make to existing science curriculum materials to promote students' engagement in these five inquiry practices? Findings from the case studies of the six preservice teachers help illuminate the kinds of adaptations the preservice elementary teachers made to enhance opportunities for students to engage in each of the five essential features of inquiry. In the sections that follow, I present cross-case analyses to illustrate how the preservice teachers adapted existing curriculum materials to address each of the five essential features of inquiry.

Adaptations to Engage Students in Scientifically Oriented Questions and Questioning. In inquiry-based science, students ask and engage in investigations to answer scientifically oriented questions to develop understandings of natural phenomena. As shown in Table 4, the preservice teachers were able to increase the inquiry subscores for the first essential feature of inquiry, engaging students in scientifically oriented questions and questioning, in both RT assignments. There was no statistically significant difference between the change in inquiry subscores for engaging students in scientifically oriented questions and questioning across RT1 and RT2 lessons, $t(46) = -1.63$, $p = .11$, $d = 0.36$. These two sets of findings from the preservice teachers' RT lessons suggest they were consistently effective at improving students' opportunities to ask and answer scientifically oriented questions in their planned RT lessons.

Findings from the case studies of the six preservice teachers help illuminate the kinds of adaptations the preservice elementary teachers made to their RT lessons to enhance opportunities for students to ask and answer scientifically oriented questions. To better promote students' engagement in scientifically oriented questions and questioning, the preservice teachers emphasized opportunities for students to articulate and make explicit questions driving their investigations, or investigation questions, as well as return to those questions to support sense making. In many cases, the science lessons they taught included investigation questions that met their criteria for effectiveness. For example, in Aliza's first lesson, which focused on soils and plant growth, she noted that

my lesson plan includes scientifically oriented questions [that] are aligned with the learning goals of (1) Consider that organic material, such as decomposed matter and worm castings, benefit plants, and (2) Set up an experiment that compares how plants develop in different materials. (Aliza, RT1, 339–332)

She wrote that these “questions also require students to provide evidence for their thinking, which will be based on the results of our experiment” (Aliza, RT1, 344). This example illustrates how the preservice teachers often evaluated their lesson plans for this essential feature of inquiry by focusing on how investigations questions were aligned with content, as well as how they promoted students’ engagement in inquiry practices such as explanation-construction.

Lesson-specific investigation questions were also an important tool in the preservice teachers’ efforts to adapt their lessons to better engage students in scientifically oriented questions when they felt their existing lesson plans to be inadequate. When this was the case, they often modified them for two distinct ways. Kim and Alex consistently emphasized using lesson-specific investigation questions to make lessons engaging and motivating for students. In Kim’s first RT lesson on plant growth, she noted that she modified the

driving question to anchor this lesson in a place that was less abstract than just “where a plant will grow best.” I tried to make it relevant to the lives of students by asking which material they would use if they wanted their garden/favorite vegetable/favorite flower to grow strong and healthy . . . this change makes the lesson more inquiry-oriented because it makes the science accessible in the everyday life of the student. . . . I hoped that having a question like this would help students engage. (Kim, RT1, 222–227)

Similarly, in Alex’s RT1 lesson on force and motion, she noted that the existing investigation question “‘What is needed to speed up, slow down, stop or change the direction of an object?’ is not as engaging or specific as another question might be” and that she “would change the driving question . . . to something more relevant to students’ lives” (Kim, RT1, 502–505). In both lessons, Kim and Alex modified existing investigation questions to connect to students’ lived experiences outside of school for purposes of promoting students’ engagement in the classroom.

The preservice teachers’ also modified or added investigation questions to better promote student sense making. More so than the other five preservice teachers, Kelly’s curriculum planning was centrally focused on the use of investigation questions to engage students in scientifically oriented questions and questioning. In the two science lessons, Kelly taught over the course of the semester, she made adaptations that engaged students in more student-directed questioning practices. Specifically, she had students co-construct lesson-specific investigation questions during the lessons. For example, Kelly’s second lesson involved her third-grade students setting up an experiment in which they tested the effect of a variety of conditions on bread mold growth. While she acknowledged that her second lesson was inquiry-oriented because, as she wrote, “the meat of this lesson *is* an investigation” (Kelly, RT2, 440–441), she also said that it was not highly inquiry-oriented because, “students are not creating the investigation question themselves . . . instead, the idea of the lesson is given to them” (Kelly, RT2, 445). To address this perceived shortcoming of the lesson, Kelly added an investigation question to her second science lesson because “including an investigation question . . . helps keep students focused throughout their investigation on what they are trying to figure out” (Kelly, RT2, 401–403). As indicated in this quote, Kelly engaged the students in formulating the investigation question that guided their examination of evidence and subsequent sense making. She said,

. . . this makes the lesson more inquiry-based because I allow students to help me form the question for our experiment. While the experiment is pre-planned, I am not telling them

what we are investigating here, but allowing them to figure it out. Further, an investigation question includes many subquestions that students can seek the answer to themselves. (Kelly, RT2, 404–408)

Following her lesson, Kelly suggested her addition of the investigation question was effective, saying, “it was good to have a question up on the board for them to look at and for me to refer to” (Kelly, RT2, 803). Kelly also said that “students had no trouble coming up with a question about how fungi survive or how they get their nutrients” (Kelly, RT2, 494–496) and indicated that she liked having students participate in developing an investigation question. This trend was consistent for Kelly throughout the study and illustrates a critical and consistent type of curricular adaptation Kelly and other preservice teachers made to better engage students in asking and answering scientifically oriented questions.

Adaptations to Engage Students in Gathering and Organizing Data and Evidence. In inquiry-based science, students give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions. As shown in Table 4, the preservice teachers were able to increase the inquiry subscores for the second essential feature of inquiry, engaging students in gathering and organizing data and evidence, in both RT assignments. There was no statistically significant difference between the change in inquiry subscores for engaging students in gathering and organizing data and evidence across RT1 and RT2 lessons, $t(46) = -1.48$, $p = .15$, $d = 0.39$. These two sets of findings from the preservice teachers' RT lessons suggest they were consistently effective at improving students' opportunities to gather and organize data and evidence in their planned RT lessons.

Findings from the case studies of the six preservice teachers help illuminate the kinds of adaptations the preservice elementary teachers made to their RT lessons to improve opportunities for students to gather and organize data and evidence. Throughout the study, the preservice teachers consistently referred to the importance of having students engage in the collection and organization of data and evidence. For example, as Kelly described at the end of the semester,

... you can't just have the question and just leave it ... you need to gather evidence ... and model it in a way by a table or whatever in a way to make sense of that evidence. If you just had an idea and just like, a lot of kids would just want to, you know, I think this is the answer because ... , it's really important to have concrete supporting evidence and facts. You need to come up valid evidence, otherwise your conclusion isn't supported. (Kelly, FI2, 235–240)

To address this essential feature of inquiry, the preservice teachers made a variety of adaptations focused on making lesson activities data-producing, engaging students in considering and negotiating what counts as evidence, and scaffolding students to collect and organize data. The variation in the specific kinds of adaptations they made was often largely a function of the specific science lesson plans with which they worked. For example, Alex's RT2 lesson focused on energy transfer. In the original lesson plan, students' were provided opportunities to view a vicarious pictorial example of each one of five different types of energy transfer. However, Alex modified her RT2 lesson to afford students' more

substantial opportunities to observe phenomena because she did not feel that opportunities provided in the original lesson plan were sufficient. For example, to illustrate mechanical energy, she noted that she used “the toy provided in the curriculum materials, but I also brought a rubber band and a paper crimper and pictures of clock gears, a wrecking ball, and an egg beater to help students think about additional examples” (Alex, RT2, 183–187). She described how she would scaffold students’ observations and sense making, saying,

I’ll ask students to describe [each example] first. Like “what is this toy like?” and then I’m going to wind it up and have it move and be like “describe the toy before I wound it, after I wound it” and then I’ll [ask] “was energy transferred? how do you know?” Hopefully we’ll define together that mechanical energy is associated with movement. (Alex, Preenactment Interview 2, 277–283)

After her lesson, she reflected that “[students] were observing and using the observations as evidence for our definitions of energy” (Alex, Postenactment Interview 2, 451–452). Alex’s curricular adaptations ultimately provided students multiple forms of evidence to use to categorize and make sense of different forms of energy.

Similarly, Mike’s RT2 lesson involved his third-grade students using various tools and materials as models of bird beaks and types of food to explore species adaptation. Mike wrote that his adaptation involved “the addition of a data collection table” in which he had “each student write which tool they had and then record how much food they were able to gather at each station” (Mike, RT2, 127–128). While Mike noted that there was a student journal page to go with the lesson, he felt as though it was not effective and students would “not collect any data to support their conclusions” (Mike, Preenactment Interview 2, 311). Mike argued that his addition of this data collection table “definitely . . . made my lesson more inquiry-oriented” (Postenactment Interview 2, 202), saying,

I think the major thing is to have them practice gathering [data] . . . a lot of the lessons that I was doing . . . never had data collection tables or anything, [students] were just told to remember [data] in their head and recall or whatever. I felt it was important to get students to just collect data. In both of my lessons I created worksheets for them to fill in information just to get them in the habit of being able to gather information and we talked about analyzing. I think it’s important to start off right away in your science lessons either to create a science notebook or something for them to be able to record their own observations or data, even if you don’t specifically tell them to. (Mike, FI2, 171–177)

This adaptation, which added opportunities for students to record and make sense of data, ultimately made Mike’s lesson more inquiry based than the original lesson plan.

However, the preservice teachers’ adaptations sometimes resulted in opportunities to collect and organize data in their RT lessons that were more student directed although not necessarily more effective. Aliza (RT1) and Kim (RT1) both taught the same lesson from the same fourth-grade science unit in which students set up an experiment to test plant growth under different conditions (organic vs. inorganic materials). Both preservice teachers adapted their lessons in ways to make existing opportunities to engage in data collection and organization more student directed, although not necessarily more inquiry based. Both Kim and Aliza had students discuss and negotiate, as a class, what specific variables they could and should measure as effective evidence of plant growth. This was

part of broader whole-class discussions each facilitated to support students to set up their plant experiments in the lesson. Aliza argued that her lesson adaptation “makes the lesson more inquiry-oriented” because the lesson “elicits students’ ideas instead of feeding them ideas and engages them in scientifically oriented questions” (Aliza, RT1, 734). She also suggested that “students will remember the [data] criteria we are looking to observe better if they come up with it themselves than if I just give it to them” (Aliza, RT1, 698–699). Similarly, Kim noted that the class discussion of the experimental design “was a positive thing” and “ended up just like being the tool that they needed to be recording some of their thinking and the thinking that we were doing collectively as a group” (Kim, Postenactment Interview 1, 149–150). While these adaptations did not ultimately make Kim and Aliza’s lessons more inquiry oriented, it is evidence that they too were emphasizing students’ collection and organization of data and evidence in their curriculum planning.

Adaptations to Engage Students in Formulating and Communicating Evidence-Based Explanations. In inquiry-based classrooms, students formulate, communicate, and justify explanations from evidence to address scientifically oriented questions. To report and discuss these results, I combine two of the five essential features of inquiry: *formulating explanations from evidence* and *communicating and justifying explanations*. The preservice teachers articulated an inherent interconnectedness between constructing and communicating explanations, to varying degrees rejecting the distinction made between the two. For example, Aliza noted,

... any form of their expressing their thinking would be communicating and justifying, right? ... maybe it would be assumed that if a student can communicate whatever the results then they understand it themselves ... it’s just ... the whole explaining, I don’t know how you would really be able to separate that, I guess ... cause to me explaining sounds like something that you would do to other people. (Aliza, FI1, 331–342)

Similarly, Kelly noted the importance of “using evidence to back up your communication and explanations” and “really pushing [students] to communicate how they know what they are telling me, like the why” (Kelly, FI2, 334–337). Mike also argued inquiry is “where students not only predict and carry out an experiment, but also analyze their information to make a supported conclusion that they communicate” (Mike, Concluding Journal, 13–14). For all six case study preservice teachers, these two criteria were largely inseparable in the adaptations they made to their lessons.

The preservice teachers were able to increase the inquiry subscores for these two essential features of inquiry, *engaging students in formulating explanations from evidence* and *communicating and justifying explanation* in both RT assignments, as shown in Table 4. As with the other essential features of inquiry, there were no statistically significant differences between the change in inquiry subscores for *engaging students in formulating explanations from evidence*, $t(46) = -0.71$, $p = .48$, $d = 0.18$, or *communicating and justifying explanations*, $t(46) = 0.55$, $p = .59$, $d = 0.11$, across RT1 and RT2 lessons. These two sets of findings from the preservice teachers’ RT lessons suggest they were consistently effective at improving students’ opportunities to formulate and communicate explanations in their planned RT lessons.

Findings from the case studies of the six preservice teachers help illuminate the kinds of adaptations the preservice elementary teachers made to their RT lessons to improve

opportunities for students to formulate and communicate evidence-based explanations. The specific adaptations they made were the result of their efforts to enhance the lesson plans they used to better engage students in specific features of inquiry they identified as lacking. There were two types of adaptations evident in the preservice teachers' RT lessons that they used to better support students' formulation and communication of explanations. Lauren's adaptations, for example, focused on having students explicate and justify their existing explanations for scientific phenomena at the beginning of her lessons. Both of her RT lessons were introductory lessons that did not include substantial postinvestigation sense-making components. As a result, she had to find unique ways to support students' formulation and communication of explanations. In Lauren's second lesson she had her third-grade students provide evidence for the knowledge claims they contributed to the "Know" column in the Know–Want to Know–Predict–Learned (KWPL) chart she had students construct about the moon. Specifically, she added an element to her lesson in which students were asked to provide the source of their ideas about lunar phenomena, which she recorded on the KWPL chart next to their claims. She argued that this change "helped limit their contributions to more legitimate statements. It also forced the students to back their claims" (Lauren, RT2, 567–568) and "they have to justify their knowledge but that they can't say that they just know, tell them you want something more" (Lauren, Preenactment Interview 2, 244). With no postinvestigation sense-making piece to the lesson, Lauren had applied her understanding of this essential feature of inquiry to have students warrant their existing explanations as part of eliciting students' ideas.

Second, curricular adaptations the preservice teachers made also focused on supporting students' postinvestigation formulation and communication of explanations, or sense making after they had carried out new investigations and/or activities in the classroom. For example, Kim's second lesson involved her fourth-grade students constructing food web models to illustrate interrelationships between ecosystem species based on a variety of data. To better support her students' understanding of these underlying relationships, Kim added a short reflective journal prompt at the end of the lesson in which students had to explain their answer to the question "What would happen if we removed decomposers from the food web? How would this affect other organisms?" She noted that she "did this to enhance inquiry" because "students were required to use the model of the food web to generate a prediction of how the change would affect other organisms" (Kim, RT2, 163). Kim elaborated, saying,

I think that it did [better engage students in inquiry] because it asked them to take a model and really think about it and how it works and how it worked differently or not at all if a piece was missing. So and I think that that's like the inquiry way to like think about models because they're just a representation of something much larger that is like too big to understand by putting all the pieces in. (Kim, Postenactment Interview 2, 206–209)

Here, then, students used model-based data to make claims about hypothetical scenarios. This adaptation by Kim better supported students to construct evidence-based explanations about species interactions, thus making her lesson more inquiry-based. Adding or modifying opportunities for students to write postinvestigation conclusions using data was a type of adaptation observed in nine of the preservice teachers' 12 RT lessons.

Similarly, in Lauren adapted her first lesson to support students' postinvestigation formulation and communication of evidence-based explanations. The existing lesson plan

had students use evidence from a text to accurately place various organisms in their habitats within a large tree displayed on the wall of the classroom. First, rather than having students merely place organisms on the tree, Lauren modified her lesson to have “each group place their organisms on the tree mural while explaining why they were placing them where they did” (Lauren, RT1, 775), using evidence from the text they read in the lesson. Lauren noted that she hoped to use students’ explanations to have an end-of-lesson discussion in which they discussed “their strategies for placing the animals in particular spots (leaves/branches/bark/trunk)” (Lauren, RT1, 438). Like Kim, Lauren also added a journal entry to her lesson to promote student sense making in which students responded to the question “Why did you choose to place your organism where you placed it on the tree?” (Lauren, RT1, 445–446). Lauren wrote that the journal entry “will allow me to see what the students have taken away from the lesson with reference to what makes an oak tree a habitat, and what organisms reside in it [and] assess each student’s understanding” (Lauren, RT1, 444). These adaptations made Lauren’s revised RT lesson more inquiry based and provided students their only opportunities to formulate and communicate evidence-based explanations.

Adaptations to Engage Students in Comparing Evidence-Based Explanations. In inquiry-based classrooms, students evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding. As shown in Table 4, the preservice teachers were able to increase the inquiry subscores for the fifth essential feature of inquiry, engaging students comparing evidence-based explanations, in both RT assignments. There was no statistically significant difference between the change in inquiry subscores for engaging students in comparing evidence-based explanations across RT1 and RT2 lessons, $t(46) = -0.93$, $p = .36$, $d = 0.22$. These two sets of findings from the preservice teachers’ RT lessons suggest that they were consistently effective at improving students’ opportunities compare evidence-based explanations in their planned RT lessons.

Findings from the case studies of the six preservice teachers help illuminate the kinds of adaptations the preservice elementary teachers made to their RT lessons to improve opportunities for students to compare evidence-based explanations. The preservice teachers’ efforts to better promote students’ comparison of explanations in their RT lessons were largely evident in two types of curricular adaptations. First, their adaptations often focused on revisiting their own explanations over time. Kim, for example, modified her RT2 lesson to provide students opportunities to compare how their ideas about decomposition and soils changed over the course of a lesson. Kim described how she “added the question, ‘Where do nutrients in soil come from?’ in order to elicit students’ prior knowledge” at the beginning of her lesson to provide her students a “starting point to revise their thinking at a later time” (Kim, RT2, 121–123). To compliment question about the origins of soil nutrients, she then added an “end of class check: ‘What would happen if we removed decomposers from the food web? How would this affect other organisms?’” to allow students to compare their ideas “based on the work they did [during the lesson] to understand the model of the food web” (Kim, RT2, 540–544). She noted that to answer the final question and make a conjecture about the removal of decomposers from ecosystems, students “had to draw on what they knew about decomposers” from the lesson. Kim ultimately argued that that “by stringing together student knowledge instead of learning something new in isolation, I believe this made the lesson more inquiry oriented” (Kim, Postenactment Interview 2, 269–271).

Second, some preservice teachers made adaptations to promote students’ comparisons of their own explanations with those of their peers after engaging in an investigation or

activity. In Alex's first lesson, for example, her fifth-grade students conducted an experiment to investigate the relationship between force and motion. She modified the lesson to accommodate the construction of a class data table, saying, "we'll set [the data table] up first so they can go use that in their groups, and then we'll come back together and make another one and collect class data" (Alex, Preenactment Interview 1, 98–99). In doing so, Alex wanted to provide students the opportunity to explicitly compare the explanations they constructed from the experiment to those of their peers. She noted that "[students were] answering the questions, like 'why do you think that moved?,' 'why did it stop moving?,' 'what was the force acting on it?' . . . those would definitely be points for the discussion" (Alex, Preenactment Interview 1, 310–311). After teaching her lesson, she noted that "one of the highlights of the lesson for me was being able to have a class discussion about the concepts of friction and gravity . . . students were able to make connections back to the experiment that we conducted and find ways to think about the concepts" (Alex, RT1, 647–650). The addition of the data table and class discussion through which students compared their explanations for force and motion resulted in a more inquiry-based lesson for Alex.

In a few rare instances, the preservice teachers made adaptations that allowed students to compare their explanations over time *and* to those of their classmates, such as Mike's second RT lesson. First, Mike added a table for predictions in the student worksheet he created for the lesson so as to promote students' reflection on how their explanations had changed. He noted the importance of using data collected from the investigation to evaluate their earlier explanations, saying, "[students] can compare their answers and see if they predicted right or got it wrong" (Mike, RT2, 83–84). However, Mike also modified the discussion at the end of the lesson to provide students opportunities to compare claims about the effectiveness of the bird beaks models based on their data. The students' comparison of explanations was based entirely in a whole-class discussion that followed the modeling activity in which the students used the various tools to pick up items. He noted that in the discussion students had to "show me their table and tell me why they made their decision" (Mike, RT2, 487) to provide points of discussion of different students' claims about which tools were more effective at picking up different objects. Mike noted his "hope is students will refer back to their table to give me an answer dealing with the quantities of worms they picked up" (Mike, RT2, 88–89). Ultimately, Mike's intent with this adaptation was to support students to understand that different bird beaks are better suited for certain types of food, one of his explicit learning goals for the lesson. He noted that "even though students didn't all construct explanations I was going for, they supported it with their data (Mike, Postenactment Interview 2, 172–175). Both of these modifications better supported students to compare evidence-based explanations in Mike's RT2 lesson.

SYNTHESIS AND DISCUSSION

To learn to engage their students in science as inquiry, preservice elementary teachers need to be afforded opportunities not only to develop an understanding of what inquiry-based teaching and learning is but also to translate that knowledge into teaching practice (Bryan & Abell, 1999; Crawford, 1999, 2007; Forbes & Davis, 2008; Zembal-Saul et al., 2000). To do so, preservice teachers must engage in authentic teaching practice, an activity that is often difficult in formal, university-based teacher education programs (Ball & Forzani, 2009; Grossman et al., 2008). Engaging preservice elementary teachers in the analysis and adaptation of science curriculum materials, however, can be an accessible and

productive means through which to support their learning through professional practice (Beyer & Davis, 2009a; Davis, 2006; Dietz & Davis, 2009; Forbes & Davis, 2008; 2010a; Gunckel, 2011; Schwarz et al., 2008).

The results of this study reinforce previous research that shows preservice elementary teachers are able to adapt existing science curriculum materials to make them more inquiry based (Forbes & Davis, 2010a). However, findings reported here extend this research by illustrating that preservice elementary teachers can make effective curricular adaptations to existing science curriculum materials to better promote each of the five essential features of classroom inquiry highlighted in contemporary science education reform (i.e., NRC, 2000). Although the five essential features of inquiry framework is one of a multitude of perspectives on inquiry in the field of science education, this is an important finding given the relative absence of science education research explicitly grounded in the NRC's five-part framework (Davis et al., 2006).

In addition, past research has shown wide variation in practicing teachers' curriculum planning and enactment in regard to science as inquiry (Enyedy & Goldberg, 2004; Fogleman et al., 2010; Pintó, 2004; Roehrig & Kruse, 2005; Roehrig et al., 2007; Schneider et al., 2005; Squire et al., 2003). It is therefore a reasonable expectation that preservice teachers with limited experiences in the classroom would show similar variation in their adaptation of curriculum materials that mirror the challenges they experience learning to actually enact those curriculum materials in the classroom (Bryan & Abell, 1999; Crawford, 1999, 2007; Forbes et al., 2010; Zembal-Saul et al., 2000). However, the findings presented in this study show that preservice elementary teachers, even at very early points along the teacher professional continuum (Feiman-Nemser, 2001), can learn to engage in curriculum design for inquiry-based science.

These findings also provide insight into *how* preservice elementary teachers adapt science curriculum materials to better promote each of the five essential features of inquiry. While the types of curricular adaptations illustrated in the results likely do not represent an exhaustive list of possible adaptations teachers could make to existing curriculum materials to better engage students in the five essential features of inquiry, they do begin to help illustrate the curriculum design decisions that preservice elementary teachers make. The preservice elementary teachers emphasized eliciting and drawing upon students' existing ideas and explanations in their curricular adaptations to better engage students in constructing and communicating explanations. Accounting for students' existing ideas is a foundational component of contemporary perspectives on student learning, including elementary students' learning in science (Driver, Guesne, & Tiberghien, 1985; Metz, 2000). Yet, it often appears difficult to link, on the one hand, the need to account for students' ideas, and, on the other, essential features of classroom inquiry, within one comprehensive framework for effective science teaching and learning. Here, as shown in the Results section, the six preservice teachers commonly asked students to make explicit their existing explanations of scientific phenomena and to make predictions based on those existing explanations. These curriculum design decisions were oriented largely toward the formulation and communication of evidence-based explanations, two of the five essential features of classroom inquiry between which the preservice teachers did not differentiate. These findings provide insight into how preservice elementary teachers reconcile, through instructional planning, the general emphasis on students' ideas in science as a foundation of effective curriculum and instruction within the NRC's five essential features of inquiry framework.

To engage students in asking and answering scientifically oriented questions in the lessons they planned, the preservice teachers often adapted lesson plans to include

engaging and answerable investigation questions that asked “how” natural phenomena occur. Investigation questions and driving questions, together referred to as “anchoring questions” (Forbes & Davis, 2010c), are important features of project-based science and integral components of inquiry-fostering discourse in science classrooms (Krajcik & Mamlouk-Naaman, 2006). These overarching questions help students problematize phenomena and serve as sense-making anchors, whether over the course of a single lesson, multiless instructional sequence, or an entire unit of study. Although particularly observable in Kelly’s curriculum planning over the course of the semester, each of the six preservice teachers drew upon investigation questions as an important tool for engaging students and grounding their lessons in meaningful problems. Anchoring questions can also serve as effective tools for beginning elementary teachers as they learn to plan and engage students in science as inquiry in school contexts where science is otherwise de-emphasized (Forbes & Davis, 2010c). As such, these findings with preservice and beginning elementary teachers suggest that anchoring questions can serve as one accessible and productive instructional tool they can learn to employ to better engage their students in scientifically oriented questioning in the classroom.

Finally, the findings from this study begin to provide insight into preservice elementary teachers’ ideas about inquiry-based science teaching and learning. As other studies have found, preservice elementary teachers often articulate knowledge and beliefs about science teaching and learning that are inconsistent with science education reform (Abell, 2007; Bryan, 2003; Bryan & Abell, 1999; Haefner & Zembal-Saul, 2004; Howes, 2002). Here, this trend was evident in two ways. First, even though none of the preservice teachers explicitly emphasized comparing evidence-based explanations in their lesson plan evaluations, they effectively adapted their lessons to better engage students in this essential feature of inquiry as shown in the results. This suggests that their ideas about inquiry-based teaching and learning may be complementary to the five essential features of inquiry. This finding reinforces past research that has illustrated the importance of preservice teachers’ existing ideas and necessity of accounting for them in teacher education (Davis, 2006; Howes, 2002; Sim, 2006). Preservice elementary teachers need scaffolding to appropriate tenets of the five essential features of inquiry framework, particularly comparing evidence-based explanations, and reconcile them with their existing conceptions of effective science teaching. This is especially important since a critical tension often exists for preservice elementary teachers in reconciling the need to accomplish predetermined learning goals while still engaging students in inquiry to compare their explanations to scientific explanations (Forbes et al., 2010).

Second, as articulated in *Inquiry and the National Science Education Standards* (NRC, 2000), each of the five essential features of inquiry can exist along a continuum from more teacher directed to more student directed. In more student-directed inquiry, students ask their own questions, design investigations, and take responsibility for decisions about the validity of evidence and explanations. However, simply engaging students in a more student-directed version of inquiry practices does not necessarily equate to more effective and inquiry-based instruction (NRC, 2000). While more student-directed classroom inquiry is often appropriate, more teacher-directed inquiry (e.g., guided inquiry) is particularly critical to provide scaffolding to students who, for example, have not historically been immersed in inquiry-based learning and/or are at the beginning of longer-term investigations in which they will assume a greater degree of responsibility over time. More teacher-directed and student-directed versions of inquiry practices both serve important functions at particular instructional junctures given the needs of particular groups of students.

Here, many of the preservice teachers' adaptations aimed at better promoting specific essential features of inquiry in their lessons served to engage students in more student-directed versions of these inquiry practices. While usually not deleterious adaptations, they also did not typically enhance the opportunities the lessons afforded students to engage in the five essential features of inquiry. In the treatment of the five essential features of inquiry framework in the methods course, the affordances of inquiry practices along the inquiry continuum were explicitly discussed. Preservice teachers engaged in and critiqued both more teacher- and more student-directed versions of scientific investigations. Yet, the preservice teachers' curricular adaptations indicate that they believed they were making their lessons more inquiry based by modifying them to be more student directed. This finding suggests that preservice teachers experience difficulty differentiating more teacher-directed and student-directed derivations of the five essential features of inquiry. For preservice elementary teachers to learn to engage their students in these essential features of inquiry, they must learn to differentiate between these two dimensions of inquiry-based science teaching and learning. I am currently engaged in follow-up research to more fully explore preservice elementary teachers' ideas about the inquiry continuum (Biggers & Forbes, accepted).

IMPLICATIONS AND CONCLUSION

Findings from this study have important implications for science educators, particularly science teacher educators, and provide crucial insight into the nature of preservice elementary teachers as learners at this early stage along the teacher professional continuum (Feiman-Nemser, 2001). First, to learn to actually engage in reform-minded, inquiry-based science teaching, preservice teachers need opportunities to participate in professional practices and critically reflect upon records of practice (Ball & Forzani, 2009; Grossman et al., 2008). Curriculum materials, as artifacts that help bridge the gap between curriculum planning and enactment, are critically positioned records of practice that can be leveraged in teacher education to support preservice teachers' learning about the teaching and learning of science as inquiry (Ball & Lampert, 1999; Loughran et al., 2004). It is important for elementary science teacher educators to foreground analysis and adaptation of science curriculum materials in science methods courses (Beyer & Davis, 2009a; Davis, 2006; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008). However, as this body of research grows, so too does the need for comparative research investigating the impact of programmatic features of specific desired outcomes in preservice teachers' learning and practice. There is a strong need for cross-institution elementary teacher education research to study these and other questions.

This study also provides crucial insight into how preservice elementary teachers might be supported to learn about inquiry-based science teaching and learning, as well as how to translate these ideas into practice, through science teacher education (Davis & Smithey, 2009; Schwarz, 2009; Zemba-Saul, 2009). Experiences for preservice teachers in methods courses could be designed and refined to emphasize the important role of anchoring questions in science, accounting for students' ideas to better promote students formulation and communication of evidence-based explanations, and what makes a science lesson more inquiry based rather than simply a more student-directed version of what already existed. Foregrounding these principles of inquiry-based teaching and learning may help preservice teachers make crucial linkages between their own existing ideas and those promoted in reform-based science teaching methods courses.

The findings from this study are encouraging in that they suggest preservice elementary teachers are capable of making curriculum design decisions that lead to more inquiry-based planned science instruction (Forbes & Davis, 2010a). However, the teacher–curriculum relationship is a function of teachers’ personal characteristics, the curriculum materials they use, features of their professional contexts, and outcomes of the curriculum design process (Brown, 2009; Forbes & Davis, 2010a; Remillard, 2005). Recent research on preservice elementary teachers’ use of science curriculum materials has largely focused on interactions between two of these elements: teachers and curriculum materials (Beyer & Davis, 2009a; Davis, 2006; Forbes & Davis, 2008, 2010a; Gunckel, 2011; Schwarz et al., 2008). The in-depth, qualitative findings presented here illustrate the role-specific features of the curriculum materials played in shaping the kinds of adaptations the preservice teachers made and reinforce the powerful influence they have on novice teachers’ instructional decision making for science (Forbes & Davis, 2010a). However, future research in this domain should focus on how these interactions are embedded in broader programmatic contexts to provide a more robust explanatory basis for *why* preservice teachers critique and adapt science curriculum materials in the ways that they do.

These findings also have implications for supporting in-service elementary teachers’ learning to engage students in the five essential features of inquiry. A one-semester methods course does not afford sufficient time to adequately prepare preservice teachers to be expert elementary science teachers. Teachers need ongoing, long-term support over many years to learn to better engage students in inquiry in the classroom. Curriculum developers, for example, can design educative curriculum materials (Beyer & Davis, 2009b; Davis & Krajcik, 2005) for elementary teachers that explicitly support elementary teachers’ learning and curriculum design practices. Although the preservice teachers here were able to adapt science curriculum materials to better promote the five essential features of inquiry in their RT lessons, there was no observable improvement in this ability over time between the two RT assignments. This finding is perhaps not surprising given the relatively short-term nature of standard, one-semester science methods courses. Future research, particularly longitudinal research, should be carried out to investigate how teachers’ learn to adapt science curriculum materials over longer periods of time.

Similarly, professional development can support in-service elementary teachers’ use of science curriculum materials to engage students in inquiry. In a new project, I am working to translate the programmatic, curriculum materials–centered approach to promoting preservice teachers’ learning discussed here into a comprehensive professional development program for practicing elementary teachers (see Forbes, Biggers, & Zangori, accepted). This project investigates in-service elementary teachers’ learning about the five essential features of inquiry and how they use existing, kit-based elementary curriculum materials to engage students in these inquiry practices in the classroom, involves the development of a pilot-tested professional development model, and provides a context for further development and refinement of the inquiry scoring rubric (see the Appendix). Each of these areas represents a critical gap in the field’s understanding of elementary teachers’ ideas about the five essential features of inquiry and how they develop over time (Davis et al., 2006). Investigating how elementary teachers at various stages along the teacher professional continuum engage in curriculum design within particular settings remains an important area of work for elementary science education researchers.

APPENDIX: INQUIRY SCORING RUBRIC FOR LESSON PLANS

	3	2	1	0
Lesson engages students in scientifically oriented questions.	Lesson uses investigation question that is feasible, worthwhile, contextualized, meaningful, ethical, and sustainable. Investigation questions and other questions are in "how" rather than "why" form. Investigation question is answerable in light of the lesson activities and other questions explicitly scaffold students' investigation and sense making.	Lesson uses investigation question that meets at least some of the criteria for effective investigation questions. Investigation question may be in "why" or "how" form. Question is at least to some extent answerable in light of the lesson activities. Lesson provides at least some additional questions teachers may use to reasonably support students' investigation and sense making.	Minimal evidence of use of scientific question and questioning. Investigation question may be present but meet few to no criteria for effective investigation questions. Questions may be in "why" rather than "how" form. Lesson makes unproductive suggestions for additional questions teachers can use to support students. Questions are likely not answerable in the classroom contexts.	No evidence
Lesson engages students in gathering, organizing, and analyzing and data.	Students collect, organize, and analyze data/evidence. Opportunities to gather, organize, and analyze evidence are linked to the investigation question and/or phenomenon under investigation.	Students do two of three of the following: collect, organize, and analyze data/evidence. Opportunities to gather, organize, and analyze evidence are at least somewhat linked to the investigation question and/or phenomenon under investigation.	Students do one of three of the following: collect, organize, and analyze data/evidence. Opportunities to gather, organize, and analyze evidence are marginally linked to the investigation question and/or phenomenon under investigation.	No evidence

(Continued)

(Continued)

	3	2	1	0
Lesson engages students in formulating explanations from evidence to address scientifically oriented questions.	Opportunities to construct explanations are connected to the evidence and data collected. Claims can be supported by evidence collected. Opportunities to construct explanations are connected to the investigation question and/or phenomenon under investigation.	Opportunities to construct explanations are less explicitly connected to the evidence and data collected and the investigation question and/or phenomenon under investigation or lesser degrees of both. Claims may be supported by evidence collected.	Opportunities to construct explanations are either marginally connected to the evidence and data collected and the investigation question and/or phenomenon under investigation or, in one case or the other, not at all linked. Claims are likely not to be able to be supported with evidence collected.	No evidence
Lesson engages students in evaluating their explanations in light of alternative explanations.	Lesson supports students to engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. Lesson supports students to do so in ways that are highly likely to lead students to explanations that are consistent with currently accepted scientific knowledge and the lesson's standards-based learning goals.	Lesson supports students to evaluate their explanations by comparing to at least one alternative explanation. Lesson supports students to do so in ways that are reasonably likely to lead students to explanations that are consistent with currently accepted scientific knowledge and the lesson's standards-based learning goals.	Lesson supports students to evaluate explanations without taking alternative explanations into account. Lesson is unlikely to lead students to explanations that are consistent with currently accepted scientific knowledge and the lesson's standards-based learning goals.	No evidence
Lesson engages students in communicating and justifying their explanations.	Lesson provides students with opportunities to share and justify their question, procedures, evidence, proposed explanation, and review of alternative explanations.	Lesson provides students with opportunities to share AND justify some aspect of their question, procedures, evidence, proposed explanation, and review of alternative explanations.	Lesson provides students with opportunities to share OR justify some aspects of their question, procedures, evidence, proposed explanation, and review of alternative explanations.	No evidence

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