Preservice teachers developing coherent inquiry investigations in elementary astronomy

Abstract

For students to attain deep understanding of scientific practices, they will need to have opportunities to participate in sustained engagement in doing science. Such opportunities begin with elementary teachers implementing coherent and well-sequenced inquiry-based investigations in their classrooms. This study explored preservice teachers (N=30) planning inquiry-based investigations for elementary students. The preservice teachers spent the first five weeks of their methods course participating in astronomy investigations followed by pair-teaching astronomy investigations once a week for five weeks to elementary students in afterschool programs. We analyzed lesson plans, teaching reflections, and pre/post astronomy content assessments. One-third of the pairs developed coherent science inquiry investigations across all of their lessons. Their reflections suggest that preservice teachers who developed coherent inquiry investigations held normative ideas about scientific inquiry and were more likely to reflect on sense-making practices than preservice teachers who did not plan for coherent science inquiry investigations in their lessons. Preservice teachers' post-instruction astronomy content knowledge was positively correlated with an increased number of lessons spent on coherent science inquiry investigations. Based on our findings, we recommend engaging preservice teachers in coherent science inquiry investigations in a single domain followed by opportunities to plan and teach elementary children in that domain.

Key words: inquiry, science practices, preservice teachers, elementary, astronomy

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Introduction

Policy documents discussing science education promote a view of classroom science that engages students in an integration of core science ideas and scientific practices in ways that reflect what we know about how students learn (NRC, 2000, 2007, 2012). The *Next Generation Science Standards* (NGSS) raises the stakes for elementary science education. The NGSS suggests how science practices grow in complexity and sophistication across the grades, thus requiring extended engagement with the practices within and across grade levels as well as across content areas (Achieve, 2013). The NGSS places a particular focus on moving science education away from the fragmented and inconsistent "mile wide and an inch deep" approach common to U.S. K-12 education (Schmidt, McKnight, & Raizen, 1997), and towards a coherent integration of science content and the practices scientists use to engage in inquiry (NRC, 2012). For students to attain deep understanding of science in ways that reflect this integration of content and practice, teachers will need to provide opportunities for their students to engage with science in ways that help them see connections within science content and practice over time.

One method of supporting this type of learning is to organize instruction using a *coherent science content storyline* (Roth & Garnier, 2006; Roth, Garnier, Chen, Lemmens, Schwille, & Wickler, 2011). Instruction built around a coherent science content storyline can "create a 'big picture' by purposefully selecting and sequencing science ideas in ways that build on one another" (Zembal-Saul, McNeill, & Hershberger, 2012, p. 48). In doing so, instruction moves away from disconnected, hands-on, science activities characteristics of the U.S. science classrooms (Roth, Druker, Garnier, Lemmens, Chen, Kawanaka, et al., 2006) and towards instruction that has been shown to improve student learning (Roth et al., 2011).

We suggest that providing students with a coherent experience that integrates science content and practices can be achieved by combining elements of the coherent science content storyline (CSCS) framework with essential practices of scientific inquiry through a *coherent science inquiry investigation*. The term *investigation* identifies the unit of analysis under study, as an investigation can span multiple days or lessons. The term *science inquiry* then highlights what needs to be coherent within the investigation. We considered a coherent experience in the practice of scientific inquiry as having the following characteristics: students have the opportunity to construct explanations based on evidence for scientific phenomena, in response to a scientific question or problem statement (NRC, 2000). Such an investigation may also engage students in additional science practices, such as the use of models and modeling, planning and carrying out an investigation, or communicating and justifying explanations to peers (NRC, 2000, 2012). However, in the interest of a unified analysis of whether or not preservice elementary teachers plan lessons around a coherent science inquiry investigation rather than disconnected science activities, we examined how they provide opportunities for students to engage in the *connections* between questions, evidence, and explanations.

The coherent science inquiry investigation framework parallels elements of the CSCS. A CSCS uses a goal statement or focus question to organize instruction; a coherent scientific investigation is also guided by a question or statement. In CSCS instruction, activities and content representations are matched to the learning goal and sequenced to support learning; in a coherent science inquiry investigation, activities and content representations are selected to help students answer the scientific question by gathering data and constructing an explanation, sequenced such that students are supported in making sense of evidence rather than confirming an answer provided by the teacher. Further, both instructional frameworks focus on making appropriate connections and sequencing of content: for example in a coherent scientific investigation, one investigation's conclusion can lead to a new question that builds on previous findings and wonderings forming new connections across the content.

While previous studies have explored how teachers and preservice teachers adapt curriculum and engage elementary students in inquiry (e.g. Biggers & Forbes, 2012; Davis, 2006; Forbes, 2011, 2013; Forbes & Davis, 2010a; Hapgood, Magnusson, & Palinscar, 2004; Metz, 2004; Siry, Zeigler, & Max, 2012; Varelas, Pappas, Kane, Arsenault, Hanks, & Cowan, 2008), limited research has explored how preservice teachers' create coherent science investigations for elementary students that attempt this integration of content and practice. Prior research suggests that elementary teachers favor the use of hands-on "activities that work," resulting in a conceptually fragmented science curriculum (Appleton, 2002, 2003); therefore, more research is needed which explores the extent to which preservice teacher prioritize these coherent investigations over disconnected hands-on science activities and what methods might be employed to support them. Therefore, we examined how preservice teachers' develop coherent science investigations in the context of their elementary science methods course as a step towards understanding how to help teachers implement instruction around core disciplinary ideas and science practices (NRC, 2012; Achieve, 2013) in ways that will support student learning through coherent science experiences (Roth et al., 2011).

Elementary teachers' ideas about teaching science as inquiry

New elementary teachers (including preservice teachers and teachers with less than five years experience) face several challenges in planning scientific investigations for their students. We first consider new elementary teachers' knowledge and beliefs about science inquiry. This is a complex construct to consider in terms of how teachers view inquiry in their teaching as use of this construct draws on their knowledge of the features of inquiry as well as their beliefs about how inquiry should be used in teaching. Yet, this distinction between teachers' knowledge and beliefs becomes blurry when attempting to analyze teacher thinking and action in classroom practice (Avraamidou & Zembal-Saul, 2010; Gess-Newsome, 1999). We therefore considered literature on new elementary teachers' ideas about inquiry and beliefs about inquiry-based pedagogy while also recognizing the difficulty in drawing this distinction.

New teachers' beliefs about the nature of science may lack sophistication and confuse science procedures with the nature of science (Brickhouse, 1990; Davis, Petish, & Smithey, 2006; Roehrig & Luft, 2004; Schneider & Plasman, 2011). Though some new teachers may describe inquiry as including questions and evidence, others believe hands-on activities and discovery-based approaches are science inquiry (Schneider & Plasman, 2011). However, Davis et al. (2006) suggest that most researchers focused on preservice teachers' understanding of specific skills rather than inquiry practices, which may limit the extent to which we can hypothesize about preservice teachers' ideas about coherent science inquiry investigations.

New teachers' beliefs and prior science education experiences may also influence the extent to which they engage their future students in scientific inquiry. In a study of two first-year elementary teachers, Avraamidou and Zembal-Saul (2010) described the influence of teachers' knowledge of science teaching and beliefs on their practice. These well-started beginning teachers engaged their students in the practices of science in ways consistent with their beliefs about science teaching. However, the two teachers differed in the extent to which they supported their students in sense-making practices of generating claims based on evidence. These differences in their knowledge of science teaching were also reflected in their personal beliefs about teaching science inquiry and may be related to differences in their prior science learning experiences; one had extensive college-level reformed-based science courses while the other had only traditional science experiences prior to their science methods course.

New teachers may also face challenges in teaching science because of limited or incomplete content knowledge, affecting their choices when teaching science (Akerson, Morrison, & Roth-McDuffie, 2006), because they are typically not science majors (Gess-Newsome, 1999; Jones & Edmunds, 2006). Prior research suggests there is a significant positive relationship between elementary teachers' content knowledge and the extent to which they implement inquiry-based science lessons (Luera, Moyer, & Everett, 2005). Some elementary teachers have difficulty incorporating their content knowledge in their teaching, suggesting that their understanding of inquiry pedagogy is separate from their knowledge of the content (Alonzo, 2002). New teachers' limited content knowledge also points to the challenges they face with representing content appropriately for their students (Zembal-Saul, Blumenfeld, & Krajcik 2000), implying challenges for planning investigations. Content representations refer to teachers' knowledge of topic-specific instructional strategies. This can include analogies, models, demonstrations, and investigations. It can also include how they use an understanding of students' beliefs and abilities to structure and sequence interventions to appropriately address students' prior knowledge and their learning goals.

Researchers have also studied how new elementary teachers adapt science curriculum towards addressing their personal knowledge and beliefs about teaching science. Though preservice teachers are capable of critical analysis of instructional materials, they do not often focus on how science concepts are represented and instead see inquiry as an opportunity to engage children's interest (Davis, 2006). Preservice elementary teachers are capable of shifting lesson plans to be more inquiry-focused, but the curriculum itself is also a mediating factor in the final inquiry-orientation of adapted lessons (Forbes, 2011; Forbes & Davis, 2010a; Gunckel, 2011). Further, the context in which the preservice elementary teacher enacts his or her lessons also influences the inquiry-orientation of the lessons; these contextual factors may include school norms of curriculum material use, time constraints, and decisions made by preservice teachers' mentor teachers (Forbes, 2013).

Support for New Elementary Teachers Engaging Students in Science Investigations

Prior research points to potential methods to ameliorate the challenges new teachers face in developing coherent science inquiry investigations. When preservice elementary teachers have the opportunity to take inquiry-based science content courses, they are better prepared to develop inquiry-based lessons than when they only take traditional college science courses (Avraamidou & Zembal-Saul, 2010; Haefner & Zembal-Saul, 2004; Luera et al., 2005). And when provided with a methods course that is structured to support their understanding of science practices, they are capable of adapting curricula in ways that provide students with opportunities to engage in science practices (Forbes, 2011; Forbes & Davis, 2010a). Forbes (2011) examined the ways in which preservice teachers adapted science lessons. The preservice teachers were able to develop investigation questions that drove the lessons, increase opportunities for students to gather data as evidence, and provide more structure for how to record and make sense of their data. The preservice teachers placed additional focus on supporting students' opportunities for constructing evidence-based explanations, such as including reflective journal prompts or by using models and representations to support their reasoning. These studies suggest that the extent to which preservice teachers' design inquiry-based lessons depends on the nature of their content courses and opportunities afforded by their methods courses to develop their understanding of science practices.

Providing preservice teachers' with opportunities to engage in cycles of teaching and reflection may also support increased sophistication in their use of inquiry-based pedagogy. Zembal-Saul, Blumenfeld, and Krajcik (2000) investigated a pair of preservice teachers designing and delivering two cycles of planning, teaching, and reflecting on connected sets of three lessons for elementary students in their fieldwork placement. Providing structured opportunity to reflect on their teaching, may have resulted in the improved engagement with science inquiry over time: in their second teaching cycle, the preservice teachers provided more opportunities for students to engage with appropriate phenomena first-hand and more opportunities for their students to engage in science practices, such as constructing explanations by identifying patterns in data. At the secondary level, Lotter, Singer, and Godley (2009) also found that preservice teachers use of inquiry with their students improved after multiple cycles of teaching and reflection. The preservice teachers' views on inquiry and ability to engage their students in the practices of science increased in their second teaching opportunity. These improvements in the preservice teachers' use and understanding of inquiry were a result of the guided reflections they made on prior teaching experiences. Reflection by preservice teachers can facilitate their pedagogical growth and make their beliefs visible when they are given proper support and scaffolding (Melville, Fazio, Bartley, & Jones, 2008).

These studies investigating new teachers moving towards proficiency in science inquiry pedagogy point to the importance of considering how new teachers' knowledge of science inquiry may shape their choices in planning inquiry experiences for their students. They also suggest that new teachers' understanding of the science content, the nature of the available science curriculum, the particulars of their teaching context, and opportunities to reflect on their teaching influence how they develop science inquiry lessons. We drew upon these findings to design an elementary science teaching methods course in order to investigate a potential method of supporting preservice teachers in planning coherent science inquiry investigations and to examine the extent to which they planned for these coherent experiences over disconnected, hands-on activities. Thus, the following research question guided the study: How do preservice teachers' relevant science content knowledge, use of curricular resources, and understanding of scientific inquiry relate to their development of coherent science inquiry investigations?

Methodology

Study Design

This study used a mixed-methods design to investigate how the experiences in an elementary science methods course supported preservice teachers in creating coherent inquiry science lessons around astronomy phenomena appropriate to elementary grades. We combined qualitative analysis of the preservice teachers' lesson plans and reflections with quantitative analysis of a pre-post astronomy content assessment to look for relationships between their ideas about inquiry, use of curricular resources, and relevant astronomy content knowledge with their success in developing coherent science inquiry investigations. This allowed us to better understand the preservice teachers' choices in lesson planning by converging on variables that influenced their design process and subsequently considering how the methods course influenced those variables.

Research Context: Elementary Science Methods Course

The study took place within three sections of an elementary science methods course at a small University in the northeastern U.S. The course was primarily taught by the first-author, who was aided by a second methods instructor, not associated with this research. Preservice teachers' experiences were designed around the features of a social constructivist model of learning (Krajcik & Czerniak, 2007): active engagement with phenomena, use and application of knowledge, engagement with multiple representations, participation in learning communities, and authentic tasks. The course was designed using a coherent science investigation framework with experiences sequenced to support preservice teachers in developing an understanding of this approach to science teaching. One level of coherence was achieved through a focused engagement in a single domain of science: the astronomy of celestial motion. During the first five weeks of the course, the preservice teachers were engaged in coherent science investigations around celestial motion phenomena. This was followed by five weeks of fieldwork where the preservice teachers wrote and then taught lessons on the same celestial motion topics. We will discuss the nature of these two components of the course in more detail below. The course continued for five additional weeks; however, that portion of the course was not analyzed in the current study.

During the first five weeks of class, the preservice teachers were guided through an interrelated series of investigations in celestial motion, led by the driving question “How and why do celestial objects appear to move in the sky?” This was broken down into smaller investigation questions addressing the apparent motion of the Sun and stars and the changing lunar phases. The preservice teachers engaged in making first-hand observations of how shadows move, the Moon’s appearance, and the stars at night. In class, the instructor led the preservice teachers in developing representations of how these objects move or appear to change over time. They also worked collaboratively to develop models that explain their observations, such as working with a globe and a lamp to explain the Sun and stars’ apparent motion.

Their engagement in the methods course also included opportunities to critique an elementary astronomy curriculum, the *Sun, Moon, Stars* (FOSS, 2007). This practice of engaging preservice teachers in rounds of curriculum critiques has become an important feature of many reform-based science methods classes (e.g. Davis, 2006; Forbes, 2011; Gunckel, 2011). During these written critiques, preservice teachers were asked whether the FOSS curriculum would engage students in a coherent inquiry investigation and to suggest modifications for the lessons if they were to teach them during fieldwork. The instructor focused the preservice teachers' attention on how the curriculum and their own experiences conducting investigation in the course provided examples of how to engage children in scientific inquiry, with a particular focus on the connection between a scientific question, interrogating data for evidence, and constructing explanations to respond to the question and using evidence (NRC, 2000).

For the second 5-weeks of the course, preservice teachers wrote and taught a series of lessons, once a week for five weeks, in afterschool programs for K-6th grade students. Each lesson lasted approximately 45 minutes. One undergraduate section taught in an urban public school's afterschool program while the other taught at a suburban private school; the graduate section taught at an urban environmental center. Each pair of preservice teachers worked with the same group of 4 to 12 children each week; children were grouped by grade level. The preservice teachers' assignment was to teach a single coherent science investigation during their time in the field; therefore, the pairs often worked together to develop an overall plan for the lessons. Each week, the preservice teachers had the following opportunities for feedback on their lessons: 1) written comments on the lesson plans from the second methods instructor, 2) whole class discussion after each lesson was taught, and 3) written feedback by the primary methods instructor based on observation of their teaching. Finally, the preservice teachers wrote weekly reflections on the enactment of the lessons. In their reflections, they discussed how they (or their partner) engaged their students in scientific inquiry during the lesson.

Participants

All preservice teachers in each section of elementary science method participated in the study (N = 30). Participants were primarily female (n=29) and European American (n=23). We used pseudonyms for the participants, as listed in Table 2. Two sections were for undergraduates (n=18) while the third was for graduate students in a post-baccalaureate certification program (n=12); the instruction and assignments were identical across sections. The graduate students came from variety of backgrounds in terms of their bachelor degrees but were required to meet the same certification requirements as the undergraduates. One undergraduate participant had previous experience teaching preschool. Many of the preservice teachers in the graduate level course had 1-2 years of experience teaching: six in preschool and one each in elementary and high school. Two participants remembered studying astronomy in high school and one in college, two more indicated that they may of studied astronomy in high school, while the rest indicated no prior study or only limited experience in elementary and/or middle school.

Data sources

Three forms of data were collected and analyzed for this study: five lesson plans per teaching pair, a pre/post astronomy content assessment per teacher, and five teaching reflections per teacher. The teachers were given the following instructions for their fieldwork assignment:

> Your goal is to develop and teach an inquiry investigation on elementary school astronomy. You and your partner will be writing lesson plans for each day of instruction. You and your partner should pick some aspect of the *FOSS Sun, Moon, and Stars* curriculum to focus on with the children. You may also use any other resources to help you design your instruction but choose materials that will help you develop an investigation around astronomy that relates to what we have been doing in our own investigations of astronomy.

Pairs co-wrote the first of the five lessons; subsequent lessons were written and taught by one partner as the lead. While most teachers worked in pairs, one could not attend fieldwork at the same time as the others and did her fieldwork on a different day. This resulted in one trio of preservice teachers planning together in that section of the course. A total of 77 lesson plans were collected and analyzed.

After each lesson, each preservice teacher submitted a written reflection on their students' opportunities for participating in science inquiry (both for their own and their partner's lessons) in response to the following prompt:

> In your reflection, discuss where you saw students having the opportunity to participate in scientific inquiry as a part of your investigation. In other words, think back to what we have identified as "doing science as scientists do science" and discuss the ways you and your partner helped the students engage in doing science.

A total of 148 reflections were analyzed (two reflections were not submitted by one teacher).

An astronomy content assessment was given on the first day of class and again after fieldwork. The assessment combined items from two existing astronomy assessments: the *Astronomy Diagnostic Test* (Hufnagel, 2002) and *MOSART* (Sadler, Coyle, Miller, Cook-Smith, Daussault, & Gould, 2010). Items were selected to align to the specific conceptual areas targeted by the astronomy instruction in the first 5-weeks of the course, which were also the topics designated for the fieldwork lesson plans. Therefore, the assessment covered: apparent motion of the Sun, Moon, and stars; explanations for apparent celestial motion; change in lunar phases; explanations for lunar phases; size and scale of the Solar System and stars.

Data analysis

We analyzed each pair's five lesson plans to examine the extent to which the preservice teachers were able to develop coherent science inquiry investigations, and to identify the curriculum resources they used to develop their investigations. We then analyzed the individual reflections to help us understand the relationship between their understanding of scientific inquiry and their choices in planning coherent science inquiry investigations. Finally, we analyzed astronomy content assessments to investigate how preservice teachers' successes in developing coherent science inquiry investigations relate to their relevant astronomy content knowledge. The detailed analysis procedures are provided below.

Lesson plans: We developed a coding protocol that includes four categories relating engagement in inquiry-based investigations: investigation question, use of investigation question, data collection, and explanation. Within each of these categories, we developed codes that reflect *INSES,* as well as codes that arose from the nature of the choices the preservice teachers made in their lesson planning; these codes can be found in Supplementary Appendix A. Some categories were applied to individual lessons while others looked at connections *between* practices and *across* lessons. The authors compared coding for a sub-sets of 20 lesson plans until a minimum inter-rater reliability of Cohen's Kappa = 0.8 was achieved for each code; however one code continued to have a low Cohen's Kappa after four rounds of comparison. The code "no connection" under the explanation category reached k = 0.64. The authors both coded all lessons for "no connections" and all disagreements were subsequently resolved through discussion.

Codes were used to develop a rubric describing the Levels of Sophistication (LoS) of their science investigations. Research on teachers' design of inquiry often focuses on the level of openness in the investigation (Schwab, 1962). The level of openness is determined by the extent to which the student or the teacher determines each element of the investigation; more choices made by the students indicate a more open level of inquiry. Our LoS rubric did not focus on openness. Instead, our LoS rubric was based measuring the coherence of their investigations by examining the connections between features of inquiry (NRC, 2000): the extent to which the preservice teachers were able to design an investigation that posed a scientific question that led to constructing a scientific explanation based on evidence (Table 1).

As described in Table 1, investigations at LoS 1 – 3 start with a question or statement and lead to engaging with data in response to that question. At LoS 1 and 2, students are asked to engage in constructing explanations and, at LoS 1, the lesson plan describes how the teacher will guide students to make an explicit connection between evidence and explanation. LoS were developed through a combination of the description of inquiry from INSES and trends observed in the students' lesson plans. For example, while LoS 1 describes a normative view of how a question leads to an explanation in scientific inquiry, we found that many lesson plans lacked an explicit connection between the data students collected and how it should be used as evidence in an explanations (LoS 2).

[**Table 1** – Levels of sophistication for coherent science inquiry investigations using *INSES* criteria]

We also considered the number of lessons spent on coherent science investigations compared to the total number of lessons. To describe the extent to which they planned coherent science investigations across their five lessons, each preservice teacher was assigned a ratio score in which the number of lesson plans spent on an LoS 1 coherent investigation (or investigations) divided by the total number of lesson plans. This is labeled as *coherence measure* in Table 2. For example, consider a pair with a LoS 1 investigation that spans three lesson plans plus two additional lesson plans with just hands-on activities. Their *coherence measure* would be three LoS 1 lessons divided by the total number of lessons (five), equaling 0.6.

Two additional codes described aspects of investigations that modified the sophistication of the lesson plans. *Verification lessons* were observed when the teacher stated the investigation question but follows this with answering the question (orally or with an activity) before engaging the students in collecting data and constructing an evidence-based explanation. We also identified lessons with *problematic content representations* that, if enacted, would lead students towards scientifically inaccurate conceptions or where the investigation methods described in the lesson could not be used to answer the investigation question posed.

***Reflections*:** We used a grounded theory approach (Corbin & Strauss, 2007) to analyze preservice teachers' reflections. We began by broadly coding for instances of text (a sentence or a few sentences) that reflected their ideas about inquiry from their reflections. To insure rigor, we went through cycles of reviewing a sample of reflections, then discussing whether their ideas fit into existing codes or if new codes needed to be created. By the last rounds of reflection analysis, no new codes appeared which suggests we had saturated our coding scheme. Three categories emerged from our open coding of these reflections: normative, alternative, and pedagogical ideas about inquiry (codes are included in Supplementary Appendix B).

Normative ideas are those that reflect how reform documents define engagement in scientific inquiry (NRC, 2000, 2012). Most of the codes in the *normative* category describe engaging students in science practices, such as use of models in constructing explanations based on evidence, making predictions, or making a clear connection between question, evidence and explanations. *Alternative* ideas are those not reflected in reform-based descriptions of inquiry or scientific practices. Some examples of *alternative* codes include: the suggestion that children are doing inquiry when they engage in a hands-on activity, developing an explanation without the use of evidence, or making sure children get the right answer. Codes in the *pedagogical* ideas category describe methods or rational for designing learning environments for inquiry investigations. *Pedagogical* codes included the idea that the teacher should guide the students during their investigations and student involvement in inquiry is enhanced when students have opportunities to ask their own investigation questions, personally collecting data, and construct their own explanations. All of the *pedagogical* codes reflected normative views on teaching with an inquiry orientation (see Appendix B). As with other studies of preservice elementary teachers (e.g. Biggers & Forbes, 2012), the teachers' reflections often focused on student-centered perspectives on inquiry-based elementary science.

After the reflections were coded, we compared each preservice teacher's ideas about inquiry with his or her inquiry LoS. We grouped teachers from highest to lowest, depending on the *coherence measure*, the number of lessons at LoS 1 divided by the total number of lessons: highest (4-5 lessons of LoS 1 investigation, *coherence measure* = 0.8-1), upper middle (2-3 lessons of LoS 1, 0.4-0.6), lower middle (1 lesson of LoS 1, 0.2), and lowest (no LoS 1, 0). Then, we compared the number of reflections that they wrote about each of the three major categories of inquiry ideas (normative, alternative, and pedagogical) with their inquiry group. Finally, we took a closer look at the specific codes from each group's reflections to further illuminate the teachers' thinking about designing investigations.

Lesson plan resources: Each lesson plan included a list of curriculum resources the preservice teachers used to plan their lesson. We analyzed those lists by grouping the materials into four categories: the FOSS *Sun, Moon, Stars* curriculum that was assigned reading during the first part of the course, other lesson plans primarily found online, class investigations they participated in during methods class, and other conceptual resources that provided content and context for their investigations. We used these categories to consider the extent to which the materials and resources provided by the methods course were used to inform their development of coherent science inquiry investigations.

***Content assessment*:** Internal consistency of items was calculated using Cronbach's alpha, leading us to drop three items from the assessment to increase the consistency of the measure. The resulting Cronbach's alpha reliability of the 21-item instrument was 0.702, above the standard "rule of thumb" minimum of 0.7 (Brace, Kemp, & Snelgar, 2009). A paired t-test was used to compare pre- and post-test results. To look for a correlation between relevant astronomy content knowledge and their development of coherent inquiry investigations, a Pearson's *r* test was used to compare pre-test and post-test results with their *coherence measure*.

Limitations

The most salient limitations of this study are with regards to our knowledge of the preservice teachers' prior science experiences, their enactment of lessons, and information on their future teaching plans. First, while we were able to generate a measure of their relevant astronomy knowledge, our analysis would have been improved with additional insight into their past science experiences to understand what may have influenced their ideas about science inquiry. Second, though prior research suggests teachers often implement the lessons they plan with a high degree of fidelity (Biggers, Forbes, & Zangori, 2013; Zangori, Forbes, & Biggers, 2013), we were not able to analyze their enactment of these lessons. Finally, an understanding of the participants' trajectories towards becoming well-started elementary teachers would be improved with additional data on their next cycle of planning coherent science inquiry investigations.

Findings

In the following sections, we present findings from the lesson plan analysis illustrating the extent to which preservice teachers developed coherent science inquiry investigations. This is followed by analyses of three factors which prior research suggests may influence preservice teachers' use of inquiry in their lesson planning: the extent to which they drew on resources provided by their science methods course, their understanding of scientific inquiry as indicated by their weekly reflections, and their knowledge of relevant astronomy content as measured by the written pre/post assessments.

Coherent Science Inquiry Investigations: Lesson Plan Analyses

Each pair's five lesson plans were analyzed to determine the extent to which they planned for coherent science inquiry investigations, using the Level of Sophistication rubric (Table 1). Table 2 shows the Level of Sophistication (LoS) for each pair's lessons and the number of lesson plans that each investigation extended. For example, Alisha and Adina wrote a three-lesson LoS 1 investigation and two single-lesson LoS 1 investigations (though one had problematic content representation). The table is organized, from top to bottom, in decreasing ratio of LoS 1 investigation lessons to total lessons (*coherence measure*). Table 2 also indicates whether the teacher was an undergraduate (UG) or graduate (G) student, the topics they chose for their lessons, the grade level of students, and their prior teaching experience.

[Table 2 - Levels of Sophistication (LoS) for inquiry investigations and teaching details for each preservice teaching pair]

To help communicate our findings, we will begin by describing the typical structure of a successfully developed LoS 1 inquiry investigation. The teachers began by posing *an investigation question* that concerns a pattern of observations (such as the Sun's path or sequence of lunar phases). Children then made and recorded *observations* to determine this pattern, occasionally through direct observation of phenomena but often through use of a computer simulation or data sources brought in by the teacher. An initial *explanation* was co-constructed between teachers and students that used the evidence to develop a *representation* of Earth-based observable pattern (representation were often pictorial, but may also have been a gestured or a verbal description). The investigation then continued as the teacher encouraged children to think about *why* the observational pattern exists through a psychomotor and/or kinesthetic *modeling activity* (e.g. children pretending to rotate like the Earth to explain the Sun's daily path). This led to a new explanation that drew upon the representation developed earlier as evidence for designing or evaluating the space-based model of motion or observing orientation. In some cases, the teachers' investigation ended after the development of the representation of the Earth-based observational pattern; this still would have counted as a full LoS1 investigation as the students were engaged in answering a scientific question with an evidence-based claim. These LoS 1 investigations provided children with a coherent science inquiry experience around one science phenomenon.

First, we will consider how the teachers' lesson plans reflected coherent science inquiry experiences by planning LoS 1 investigations across the five weeks in their field placement. Four pairs of teachers created LoS 1 investigations that spanned all five lesson plans: they spent all five lessons either investigating the same investigation question, or they started with an observational investigation question (such as, *how* does the Sun appear to move?) and modified it during the lesson sequence to address a new aspect of the construct (*why* does the Sun appear to move?). One additional pair created a three-lesson plan LoS 1 investigation plus two more single-lesson plan LoS 1 investigations (though one of these had a problematic content representation). Six other pairs included LoS 1 investigations during one, two, or three of their lessons plans. Thus, more than two-thirds of the preservice teachers were able to write one or more lesson plans that engaged their students in a coherent scientific inquiry investigation and nearly half of the pairs spent three or more lessons on coherent investigations.

While the description of inquiry in LoS 1 is based on a normative goal of a coherent scientific inquiry investigation, the remaining LoS emerged as patterns in the preservice teachers' lessons. Pairs who created a LoS 2 investigation provided opportunities for students to construct explanations but did not make the use of evidence an explicit part of how children constructed explanations in the lesson plan. For example, teachers followed data collection and analysis with a broad summarizing question but no support or explicit guidance for selecting evidence to support the explanation. These were categorized as an implied use of evidence because of the temporal proximity to the data collection phase.

Other pairs only created LoS 3 or 4 investigations. LoS 3 investigations lacked an opportunity for children to construct an explanation using the data they collected, in response to an investigation question. Beth and Belinda posed several potential investigation questions but none led to collecting data. Instead, the students were engaged in a series of hands-on activities, such as making models out of play dough or coloring in worksheets to show the night side of Earth. Flora and Fran did not provide a question or clear statement to drive the investigation until their third and fourth lessons; when they did, the students did not have an opportunity to construct an explanation in response to the investigation question. Heather and Hill's LoS 4 investigations are limited by a lack of clear focus provided by a question or problem statement. Though the students engage with potential data, there was no clear purpose to this work. The students were engaged with physical and kinesthetic models as well, but with the goal of reaching a "correct answer" through a hands-on activity.

We found additional problematic aspects within a few lessons. A few teachers wrote verification lessons that began with an appropriate investigation question, which was then answered by the teacher. Nadia created three lesson plans in which she answered the investigation prompt prior to allowing the students to observe and explain the phenomena for themselves. Two pairs included a lesson with problematic content representations. Flora wrote a lesson with an inaccurate explanation for lunar phases. Alisha planned a model to use in investigating the seasons that did not accurately represent this concept.

Table 2 also shows that all five lessons for each pair did not end up on the LoS scale. Some teachers wrote lessons that focused on hands-on activities rather than engagement with any of the elements of a coherent science inquiry investigation. Dana and Di wrote three such lessons. The first lesson engaged students in learning the relative size of the Earth and Moon through a directed modeling activity. Later lessons led the students in physical and kinesthetic models of the Earth-Sun system to learn why we have seasons and why we see different constellations at different times of the year. For example, the teachers proposed to have the students use flashlights to see how the length of day changes as the Earth orbits the Sun. Thus, the teachers engaged the students with a scientific model that could yield predictions that could be tested against real-world observations. However, the students did not have an opportunity to compare or develop the model in response to evidence. These lessons were promising in terms of engaging children in relevant content representations for astronomy but fell short of engagement in scientific inquiry due to the lack of connection to evidence.

Use of Curricular Resources

To explore potential influences on the preservice teachers' development of coherent science investigations and consider why some preservice teachers were more successful than others, we considered the curriculum materials they drew upon in writing their lesson plans. As the science methods course provided several potential sources for the preservice teachers to draw on, we considered the extent to which they drew on materials provided by the methods courses versus other external resources. There were three categories of resources that came from the science methods course: class investigations, FOSS curriculum, and conceptual resources. Nearly half of the preservice teachers (44%) cited specific investigations that they participated in as students during the first five weeks as the source of their lesson plans. However, few pairs cited the class investigations for more than one or two of their lessons.

Most pairs (63%) cited the use of the FOSS curriculum in one or more lessons, with five pairs from across the inquiry levels using the FOSS curriculum in three or more lessons (C's, O's, K's, N's, and B's). Our review of the FOSS curriculum found that, while the curriculum describes methods of engaging children in science practices, it is limited in its support for coherent science inquiry investigations. For example, while focus questions are provided, such as "How does the Sun move from sunrise to sunset?", the curriculum does not help the teacher see how these focus questions can be used to guide data collection and then be answered using evidence.

All pairs (94%) except Owen and Olivia included other significant *conceptual resources* in their lesson plans. These were resources that did not explicitly give teachers direct pedagogical ideas but may have shaped their lessons through the content and context they provided. For example, many pairs used the computer simulation *Stellarium* in their lessons. This resource provided an opportunity to simulate collecting data and thus was a likely a strong influence on the lessons they were able to design. Star charts and Moon charts were another frequently used resource and provided an opportunity for their students to make comparisons of astronomical phenomena over time. Real photos of the Sun and Moon were further resources gathered as data for investigations. Some groups also used reference materials, such as non-fiction texts on astronomy. All of these resources, with the exception of some non-fiction books used by Jackie and Jade, originated in investigations the teachers experienced in the methods course or suggestions from the methods instructor.

Finally, most pairs (69%) also used *other lesson plans* – resources that they found on their own rather than introduced during the methods course. However, these were often used in only one or two lessons.

Returning to our question of how the curricular resources may have influenced their development of coherent science inquiry investigations: no pattern was observed when comparing the category of curriculum materials cited and the fraction of lessons plans spent on coherent science inquiry investigations.

Understanding of Science Inquiry

We next used the analysis of preservice teachers' ideas about inquiry, as suggested by their weekly reflections, to further interpret the choices they made in writing coherent science inquiry investigation lesson plans. Figure 1 shows the number of days each preservice teacher's reflection was coded for each inquiry categories. Most preservice teachers (80%) spent more days identifying normative ideas about inquiry than alternative ideas and nearly a third (30%) did not include any alternative ideas in their reflections. Far fewer spent the same number of days on normative and alternative ideas (7%) or more days on alternative ideas over normative ideas (13%). Thus, our initial analysis suggests that most could recognize elements of scientific inquiry during science instruction when teaching or observing a peer teaching.

[Figure 1. Preservice teachers are grouped by the *coherence measure* calculated with the number of lessons in LoS 1 divided by their total number of lesson plans (highest is *coherence measure* = 0.8-1; upper middle = 0.4-0.6; lower middle = 0.2; lowest = 0) along the x-axis. The y-axis shows the number of reflections in which each preservice teacher wrote about each of the three inquiry idea categories: normative, alternative, and pedagogical.]

We investigated the relationship between their ideas about inquiry and the coherence of the investigations in their lesson plans. Figure 1 showed each preservice teacher sorted from highest to lowest *coherence measure*, the number of lessons each pair engaged students in a LoS 1 investigation divided by the total number of lessons: *highest* group (four or five lessons at LoS 1, *coherence measure* of 0.8 – 1), *upper middle* group (two or three lessons at LoS 1, 0.4-0.6), *lower middle* group (one lesson at LoS 1, 0.2), and *lowest* group with no LoS 1 investigations across all lessons (*coherence measure* 0). Our analysis reveals that the *highest* group had only one pair of preservice teachers with a single instance of alternative ideas in their reflections, while the *lowest* group had frequent examples of alternative ideas on multiple days. The members of the *lowest* group each had more alternative instances than normative instances in their reflections. For example, Claire (*highest* group) has five reflections with normative ideas without instances coded as alternative or pedagogical ideas. In comparison Fran (*lowest* group) has two reflections with normative ideas, three reflections with alternative ideas, and three reflections with pedagogical ideas.

Another major difference between the *highest* and *lowest* groups is that the *highest* group has a greater diversity of normative ideas and that these appear across multiple days while the *lowest* group's reflections included mostly "data collection" and "making predictions" codes, resulting in less variety of codes across fewer days. All teachers in the *highest* group have "constructing explanation based on evidence" or "modeling in constructing explanations based on evidence" in their normative beliefs in multiple reflections while few in the *lowest* group reflect on these sense-making practices. The *highest* group's reflections include evaluative practices suggesting a more in depth understanding of the practices of science, while the *lowest* group did not. These evaluative practices include engaging students in evaluating how useful and effective their data was for answering their research question or evaluating whether or not their investigation had effectively answered their investigation question. For example, Claire wrote: "… next week, I plan to have the students revisit the investigation they created. I will have them analyze the results, and determine whether or not they felt that it was an effective investigation."

Then, we compared *highest* group to pairs that only developed single coherent inquiry investigation lesson plan (*lower-middle*) to consider possible differences in their ideas about inquiry. The *highest* group had only one pair with a single reflection with an alternative belief while the *lower-middle* group had pairs with multiple reflections which included a variety of alternative beliefs (e.g. engaging in skills, hands-on engagement, and participating in a modeling activity without connection to evidence). In addition, we found that while the preservice teachers in the *lower middle* group reflected on sense-making practices, such as constructing explanations based on evidence, this occurred less frequently than in the *highest* group.

We also considered the extent to which the preservice teachers reflected on the connected nature of science practices as a possible explanation for why some preservice teachers developed coherent science inquiry investigations while others did not. Carly and Claire reflected on the connection between question, evidence, and explanation across multiple reflections. Both reflected on their investigation question after the first lesson and indicated their plan for a five-day coherent inquiry investigation. Carly wrote, "…we decided our driving question will be "How and why do the sun, moon, and stars move?" This will also lead us right to scale…. I first facilitated a discussion with the students about what we have learned so far from all the data we have gathered on the topic and then I let them get to work on modeling what they have learned from the data (Reflection 1)." In this excerpt, she reflected on the inquiry question, data they gathered, and explanation through modeling based on evidence:

> I believe that this practice in modeling helped improve their inquiry skills, particularly the importance of backing up their points with reasoning and evidence because by the time of the presentations, students were asking the other groups questions like, 'How does that show the sun rises in the east?' or 'What did you mean by when you said shift?' They have begun to expect that students have evidence to support their claims. I was also glad that the students were able to show how the earth rotates. (Carly, Reflection 4)

However, only Carly and Claire consistently reflected in a way that connected their investigation question, evidence, and explanation development. And while others reflected on similar connections in one or two reflections, most of the preservice teachers' reflections did not explicitly discuss these connections.

Relevant Astronomy Content Knowledge

Finally, we examined the preservice teachers' astronomy knowledge as a potential explanation for why some pairs developed coherent science inquiry investigations and others did not. Initially, the preservice teachers had a relatively low level of knowledge of elementary astronomy, with a mean score of 7.7 (sd = 2.7) out of 21 on the content assessment. The mean score on the post-test, administered three weeks after fieldwork, was 12.3 (sd = 3.3), a statistically significant improvement ($t = 9.97$, $p<0.001$). While no correlation between their initial knowledge of astronomy and their *coherence measure* was observed, there was a significant correlation between their post-instruction astronomy knowledge and their *coherence measure* (Pearson's $r = 0.366$, $p<0.05$). This suggests that what they learned during the initial five weeks of investigation and during the process of developing lessons was related to their construction of coherent science inquiry investigations.

Discussion

Our study examined preservice elementary teachers' development of coherent science inquiry investigations and factors that may help explain their success. We developed and applied a method of coding preservice teachers' lesson plans to evaluate whether they had planned a coherent science inquiry lesson, within and across multiple lessons. Our findings suggest that, with appropriate support provided by a science methods course, many preservice elementary teachers are able to develop coherent science inquiry investigations designed to engage students in constructing explanations about astronomical phenomena. A third of the pairs were able to develop coherent investigations for all five lessons they taught in an afterschool program, starting with an investigation question that led to collecting and analyzing data and co-constructing explanations based on evidence. These preservice teachers' development of coherent science inquiry investigations suggests they are beginning to consider methods that engage students deeply with a single concept over time rather than a more fragmented approach of hands-on "science activities that work" (Appleton, 2002, 2003).

However, not all pairs developed coherent science investigations for all or most of their lessons. One third of the preservice teachers developed either a single lesson plan with a coherent science inquiry investigation (LoS 1) or no lessons at that level of coherence. Even when preservice teachers shift towards more inquiry-oriented approaches, moving towards the belief in the centrality of evidence-based explanations in science is still difficult (Zembal-Saul, 2009). In other ways, these results are promising as we consider that these were their first experiences in attempting to develop coherent inquiry investigations. Even the students who did not develop LoS 1 investigation engaged their students in opportunities to collect and discuss data as well as other scientific practices. Thus, we see an indication of a potential continuum between preservice teachers who were partially successful (including some elements of scientific inquiry, such as opportunity for collecting data, but primarily focused on hands-on activities) to those who wrote fully developed coherent investigations across all of their lesson plans.

Preservice teachers need to experience the process of learning science in the ways we hope they will teach science in their future classrooms (Haefner & Zembal-Saul, 2004; Zembal-Saul, 2009). Thus, science methods course was designed to support the preservice teachers' development of coherent science investigations through experiences with coherent science inquiry investigations and by providing examples of curricula and other resources they could use to develop inquiry-based astronomy lesson plans; these experiences helped them understand the features of inquiry as well as to develop the type of coherent understanding of astronomy needed to teach elementary students. We will discuss how our analysis suggests preservice teachers utilized these experiences and resources to inform their choices in planning science lessons.

Preservice teachers' use of resources and curriculum

Prior research suggests that an important predictor of whether new teachers will implement inquiry-based investigations in their teaching is their prior experience engaging in scientific inquiry (Windschitl, 2002). Further, long-term engagement in authentic science investigations can also shift preservice teachers' thinking towards recognizing the centrality of questions to science (Haefner & Zembal-Saul, 2004). Therefore, we considered the role the methods course played in supporting preservice teachers in planning for coherent science inquiry investigations through their engagement in coherent science investigations during the first five weeks of the course. Close to half of the pairs indicated they were drawing on the investigations from the first 5 weeks of class as a source of one or more of their lesson plans. Further, many preservice teachers used resources provided by the methods course, such as the computer simulation *Stellarium* and access to monthly star charts.

Many of the preservice teachers also cited the FOSS *Sun, Moon, and Stars* curriculum, chosen for the class to read and critique because it covered the relevant astronomy content and has an inquiry-based approach. Forbes and Davis (2010a) suggest that the most influential factor determining the level of inquiry of preservice elementary teachers' lessons was the curriculum material they chose to adapt. Thus, we considered how this particular FOSS curriculum may have supported a coherent science inquiry approach to lesson planning. Our analysis suggests that, despite having an inquiry focus, it also has limitations that would not have supported teachers in developing coherent investigations, according to our criteria, without significant adaptation from the teachers. In particular, the curriculum did not include clearly stated investigation question leading to collecting data and constructing evidence-based explanations. Research on elementary teachers suggests that their curriculum implementations often do not go beyond the level of inquiry in the original lessons (Biggers, et al., 2013; Zangori, et al., 2013); those preservice teachers who relied on the FOSS curriculum may have needed additional support to write coherent science inquiry lesson plans.

Preservice teachers' ideas about inquiry

Teachers' ideas about inquiry are reflected in the ways they enact science in the classroom (e.g. Furtak & Alonzo, 2010). The preservice teachers' ideas about what counts as "doing scientific inquiry" were related to the number of lesson plans they wrote which engaged children in coherent science inquiry investigations. Preservice teachers who developed these coherent investigations across many lesson plans identified normative scientific practices in their reflection and discussed more sense-making practices than other preservice teachers. Those who did not develop coherent science inquiry investigations across most of their lesson plans often indicated ideas that do not correspond to normative descriptions of inquiry; these alternative ideas have been observed in other studies of preservice teachers, such as thinking that hands-on activities is sufficient to count as an inquiry investigation (Biggers & Forbes, 2012; Davis & Smithey, 2009; Haefner & Zembal-Saul, 2004). Roehrig and Luft's (2004) described secondary science teachers as ranging from inquiry teachers, process-oriented teachers, to traditional teachers. The focus on process-orientation in which instructional activities are designed to help students learn science skills was observed in some of the alternative ideas in our preservice teachers though none appeared to be writing lessons from a purely traditional perspective. However, even when the teachers in our study revealed alternative views of engaging students in inquiry, many of their lesson plans and ideas about inquiry focused on student-centered instruction. Such conceptualizations are a crucial element for early career teachers in eventually developing inquiry-based classrooms (Roehrig & Luft, 2004).

The literature on teachers' ideas about scientific inquiry can be organized around two dimensions (Furtak, Seidel, Iverson, & Briggs, 2012): a *conceptual dimension*, which includes the conceptual structures, epistemic frameworks, social interactions, and procedural methods of inquiry, and a *guidance dimension* of inquiry, which examines the continuum between teacher led, to teacher-guided, to student-led or discovery approaches. While we anticipated capturing preservice teachers' reflections on the *conceptual dimension* in their reflections, we also found that the teachers chose to reflect on the *guidance dimension* – what we referred to as "pedagogical ideas." This focus on the pedagogical aspects of inquiry is not surprising given their experience in the methods course. During the methods course, the students engaged in scientific inquiry investigations and were guided to think about the epistemological features of their experiences. This experience was also blended with instruction that emphasized the pedagogical benefits of engaging children inquiry-based instructions through a socioconstructivist framework (Krajcik & Czerniak, 2007). Our findings are consistent with previous research suggesting preservice teachers "typically describe inquiry as important to incorporate to promote student interest, not to engage students in genuine scientific activity" (Davis, 2006, p. 348). This suggests that many of the preservice teachers were highly attuned to factors that will help their students learn but not necessarily for the sake of engaging a coherent science inquiry investigation. However, our analysis does not suggest these either hindered or supported their development of coherent inquiry investigations as these pedagogically focused reflections were prevalence across all the preservice teachers.

Preservice teachers' relevant astronomy knowledge

Teachers need a deep and flexible knowledge of the content to plan effective instruction (Borko, 2004). The teachers significantly improved in their relevant astronomy content knowledge after their experiences during the course. We also found a positive correlation between preservice teachers' post-instruction content knowledge and their *coherence measure*, thus adding to the literature showing that teachers need sufficient science content knowledge to develop inquiry-based instruction (e.g. Roehrig & Luft, 2004). This suggests that the coherence and sequencing of the science content focus (i.e. astronomy), through the investigations during the first five weeks of the methods course and their lesson plan writing during the second five weeks, may have contributed to their success.

A significant body of research suggests that both children (e.g. Plummer, Kocareli, & Slagle, 2014) and adults (e.g. Plummer, Zahm, & Rice, 2010; Zeilik & Bisard, 2000; Zeilik & Morris, 2003) find astronomy challenging to learn, including elementary content standards. Few teachers in our study studied astronomy in high school or college, and many did not ever remember studying astronomy; this is not surprising as astronomy may be left out of the curriculum in many middle and high schools (Plummer & Zahm, 2010). This trend suggests that without significant support in developing relevant content knowledge, elementary teachers are unlikely to engage their students in coherent science inquiry investigations.

Conclusion

The *NGSS* emphasize engaging students in a breadth of science practices across core disciplinary ideas and across grade levels. This is undeniably important, but to fully develop students' understanding of the scientific enterprise, teachers should also sequence students' experiences with science practices in coherent investigations. This study goes beyond previous studies by explicitly investigating the potential and challenges associated with preservice elementary teachers developing coherent science inquiry investigations; we explicitly examined the connections made between scientific questions, data collected, and explanation construction in their lesson plans. By analyzing their writing across five consecutive lesson plans, we were able to analyze their level of coherence whether it took place within a single lesson or across multiple lessons. Our findings suggest that many preservice teachers are capable of developing these coherent science inquiry investigations, given support for their understanding of science inquiry practices and knowledge of relevant science content.

In this study, we considered the ways in which the design of the science methods course provided this support. One critical feature of the course was the coherence and sequencing of the preservice teachers' experiences during the first five weeks of the course and the second five weeks where they engaged in planning and teaching lessons to elementary students. Part of this coherence was the focus on a single science content area, observational astronomy; the preservice teachers participated in astronomy investigations followed by opportunities to apply what they learned by writing and teaching astronomy lessons to elementary students. The differences in how scientists conduct investigations in different domains may make it difficult to compare teachers focusing on different science disciplines (Roth et al., 2006); for example, while in some fields, scientists conduct carefully controlled experiments to test their hypotheses, other fields, such as astronomy, are based on descriptive methodologies. When school science focuses on the "scientific method," students are often only exposed to experimental studies where one variable is tested in comparison to a control group, a methodology not possible in many science fields (Windschilt, Thompson, & Braaten, 2008). Our focus on observational astronomy across the preservice teachers' experiences allowed us to reduce potential variation due to differences between doing and teaching science across different domains of science within the study.

For those preservice teachers who developed coherent science inquiry investigations in their lesson plans, the science methods course appears to have influenced them in two primary ways. First, teachers with higher astronomy knowledge at the end of their lesson planning experience were more likely to produce coherent science inquiry investigations in their lesson plans. Though the literature often points out the importance of content knowledge for successful teaching, few studies have examined correlations between teachers' use of inquiry and their content knowledge (Luera et al., 2005). By narrowly focusing on one area of science across all the teachers in this study, we were able to provide evidence of this important connection.

Second, teachers whose reflections included fewer alternative ideas about inquiry and more descriptions of sense-making practices spent more of their lesson plans on coherent science inquiry investigations than other teachers. Thus, preservice teachers' reflections on inquiry further reveal their ideas of what counts as scientific inquiry and points to important aspects of their decision-making process when planning science lessons. Both of these correlations led us to emphasize the importance of providing coherence across and connection between the preservice teachers' experiences in methods course and their fieldwork opportunities.

Implications

The preservice teachers' success in planning coherent science inquiry investigations points to several implications for the design of elementary science methods courses. First, we recommend that elementary science methods courses support preservice teachers by engaging them in inquiry-based science curricula as students, followed by the opportunity to use that experience to plan and teach science lessons to elementary students (Haefner & Zembal-Saul, 2004). By focusing these experiences in the same science content area, the preservice teachers will deepen their understanding of relevant science content knowledge and be better prepared to translate their own science learning experiences into coherent investigations ready for elementary students during field work. This conceptual coherence between methods course and fieldwork assignment provides opportunities for the methods instructor to support preservice teachers, through in-class investigation examples, opportunities to critique relevant curricula, and to develop a community of teachers working towards a closely aligned goals.

Second, we recommend that methods courses plan opportunities for preservice teachers to reflect on and identify their own use of inquiry in the lessons they write and teach. In addition to the importance of reflective practices to teachers' growth (Abell & Bryan, 1997; Bryan &

Abell, 1999; Crawford, 1999; Davis et al., 2006; Lotter et al., 2009; Singer, 2005; Zembal-Saul, et al., 2000), these reflections also provide a window into the preservice teachers' understanding of scientific inquiry beyond what is revealed in their lesson plans. Methods instructors may identify alternative ideas in these reflections and plan for opportunities to address these problematic conceptualizations in future classes. We further recommend that instructors direct their preservice teachers to reflect on the connections between individual lessons, to emphasize the importance of building a coherent science curriculum over time rather than focusing on individual lessons (e.g. NRC, 2012; Roth & Garnier, 2006). This was not explicitly asked of our preservice teachers and few reflected on the connections between their lessons.

Third, preservice teachers' experiences, both engaging in investigations as learners and planning as teachers, should emphasize the importance of sense-making practices involved in developing evidence-based explanations. By first supporting preservice teachers in developing evidence-based explanations and modeling practices through in class investigations, preservice teachers will be better prepared to attempt these practices in their fieldwork experiences. However, we note that many of the preservice teachers in our study either missed opportunities to include these sense-making practices in their lessons or to discuss this aspect of inquiry in their reflections. Thus we suggest making reflection on sense-making practices an explicit part of preservice teachers' reflections on their fieldwork to help them focus on this vital aspect of doing science. If fieldwork teaching experiences are spaced out over time, such as once-a-week lessons in this study, the methods instructor would have the opportunity to address preservice teachers' ideas about sense-making practices as exhibited in their lessons and reflections.

Finally, given the influence that school culture can play on new teachers' pedagogical choices (Avraamidou & Zembal-Saul, 2010; Forbes, 2013; McGinnis, Parker, & Graeber, 2004), we suggest that using non-formal settings for fieldwork allows preservice teachers more flexibility in their lesson planning. In this study, the preservice teachers designed for and taught in afterschool programs. This out-of-school setting allowed the preservice teachers to focus on elements of teaching without the additional pressures of traditional school placements. For example, the preservice teachers may have been more successful in developing the type of coherent inquiry investigations proposed by their methods course instructor because they were not receiving conflicting requirements from a classroom mentor teacher. Given the influence of early field experiences on preservice teachers' dispositions towards teaching, it is essential that these experiences are supportive of inquiry-based practices (Forbes, 2013).

Our method of analyzing preservice teachers' use of inquiry also has implications for teacher education and research. While previous studies have considered the extent to which teachers include features of scientific inquiry in their lessons and teaching (e.g. Biggers & Forbes, 2012; Forbes, 2011, 2013; Forbes & Davis, 2010a), we focused primarily on the connections the teachers made between features of inquiry as central to our analysis. Our Levels of Sophistication rubric (Table 1) could be used as an instructional tool for methods professors to guide preservice teachers' thinking about planning investigations, as it is broad enough to include multiple investigative methods. The rubric could also be used as an analytical tool for researchers in studying how teachers develop and implement coherent science inquiry investigations, across age groups and across scientific disciplines.

These findings have further implications for the development of educative curricula, designed to support both teacher and student learning (Davis & Krajcik, 2005; Schneider & Krajcik, 2002). Educative curricula should highlight the deeply connected nature of the experiences in a scientific investigation to move away from a piecemeal perspective reflected in hands-on and skill-based lessons. Such curricula could build on the concept of the *coherent science content storyline* (Roth & Garnier, 2006), by helping the teacher learn methods of engaging children in science practices towards a deepening understanding of a single conceptual goal. In particular, this type of curricula may have helped some of the preservice teachers in this study who had limited astronomy knowledge. A lack of understanding of the connections between concepts in astronomy may have limited their ability to envision the steps of an investigation that builds towards an evidence-based explanation. In doing so, educative curricula should provide explicit examples of the *types of investigation questions* that are feasible for elementary astronomy investigations and *how to connect* those questions to appropriate data collection methods. Lesson plans that were not classified in the more sophisticated levels of inquiry-based investigation often did not connect a clear investigation question with engagement in data collection. Slater, Slater, and Shaner (2008) suggest that generating scientific questions that are both ready and worthy to investigate is the most difficult element of the scientific process for students. However, science curricula often do not provide teachers with questions that support scientific investigations (Forbes & Davis, 2010b; Kesidou & Roseman, 2002). Another limitation we observed in some preservice teachers' lessons was the lack of explicit connection between their plans for their students to collect data and opportunities to construct explanations. Thus, curricula should provide explicit support for teachers in how to support students in moving from collecting data to using evidence purposefully in constructing an explanation.

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Table 1 – Levels of sophistication for investigations using *INSES* criteria

	Description of level	Lesson plan codes[1]
Level 1	Investigation question leads to examining data for evidence towards answering the question. An explanation is constructed in response to the investigation question and explicitly uses evidence as support.	All four codes must be connected to the same question/statement: **Investigation Question**: Question or Investigation statement **Use of IQ:** Data collection, responds to data **Data:** Connected **Explanation:** Connected
Level 2	Investigation uses an investigation question that leads to interrogating data for evidence but leaves the connection between evidence and explanation *implied*.	All four codes must be connected to the same question/statement: **Investigation Question**: Question or Investigation statement **Use of IQ:** Data collection, responds to data **Data:** Connected **Explanation:** Implied
Level 3	Lessons allow children to engage with data in response to a question but children are not guided to construct an explanation in response to the	All three codes must be connected to the same question/statement: **Investigation Question**: Question or Investigation statement **Use of IQ:** Data collection, responds to

	investigation question.	data **Data:** Connected
Level 4	Children engage with data but not in response to a scientific question.	Does not include an investigation question or statement. **Data**: Not connected

[1]Detailed descriptions of categories and codes are found in Appendix A.

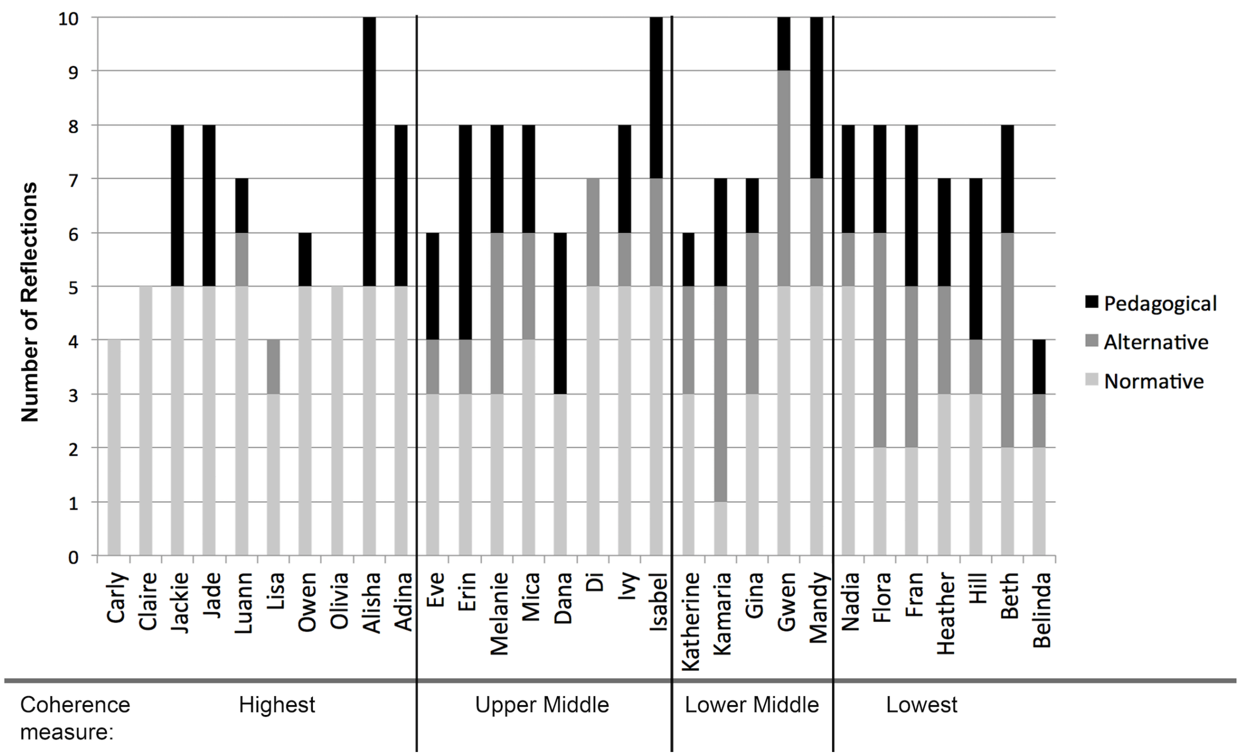
Number of Reflections
0
1
2
3
4
5
6
7
8
9
10
Pedagogical
Alternative
Normative
Carly
Claire
Jackie
Jade
Luann
Lisa
Owen
Olivia
Alisha
Adina
Eve
Erin
Melanie
Mica
Dana
Di
Ivy
Isabel
Katherine
Kamaria
Gina
Gwen
Mandy
Nadia
Flora
Fran
Heather
Hill
Beth
Belinda
Coherence measure:
Highest
Upper Middle
Lower Middle
Lowest

Table 2 – Inquiry levels of sophistication and teaching details for each preservice teaching pair

	Graduate or Under-graduate (UG)	Coherence measure[1]	Level 1	Level 2	Level 3	Level 4	Lesson plan topic(s)	Grade levels	Prior teaching experience
Carly[a] & Claire	UG	1	5 lessons				Explaining Sun's apparent motion	4th	None; none
Jackie[a] & Jade	Grad	1	5 lessons				Changing appearance of the Moon	K	1 year PreK; 2.5 years PreK
Luann & Lisa	Grad	1	5 lessons				Explaining phases of the Moon	4th	None; 1+ years PreK
Owen & Olivia	Grad	1	5 lessons				Explaining Sun's apparent motion	3rd - 4th	2+ years el. and MS; 1 year PreK
Alisha & Adina	UG	.8	3 lessons, 1				Explaining Sun's apparent motion (3 lessons), Sun's	2nd	None; none

			lesson, 1 lesson*			appearance, seasons		
Eve & Erin	UG	.6	1 lesson, 1 lesson, 1 lesson			Seasonal constellations, circumpolar constellations, size and scale of solar system	4^{th} - 5^{th}	None; none
Melanie[b]	Grad	.6	1 lesson			Phases of the Moon	2^{nd}	1 year PreK;
Mica[b]		.6	1 lesson, 1 lesson					Kindergarten;
Mandy[a, b]		.2		1	1 lesson			none

					lesson			
Dana & Di	UG	.4	2 lessons			Size and scale, Explaining Sun's apparent motion (2 lessons), seasons, stars' motion	3rd	None; none
Ivy & Isabel	UG	.4	2 lessons		1 lesson	Sun's apparent motion (2 lessons), nature of planets, stars in day and night	K	4 years early learning center; none
Katherine & Kumaria	Grad	.2	1 lesson	1 lesson, 1 lesson	3 lessons	Sun's path, day/night cycle, size and scale of Sun, Earth, Moon	K-1st	5 years H.S.; Som PreK
Gina & Gwen	UG	.2	1 lesson		1 lesson,	Size and scale, using a compass, apparent	K-1st	None; none

				1 lesson		motion, constellations		
Nadia	Grad	0	1 lesson, 3 lessons **			Apparent motion of constellations, seasonal constellations (3 lessons)	K-1st	None
Flora & Fran	UG	0		1 lesson, 1 lesson *	1 lesson	Relative size of Earth and Moon, lunar phases, eclipses	2nd - 3rd	None; none
Heather & Hill	UG	0			2 lessons, 1 lesson, 1 lesson	Phases of the Moon (2 lessons), eclipses, seasonal and circumpolar stars	6th	None; none

Beth & Belinda	UG	0		1 lesson	Day/night cycle, lunar phases	3rd	None; none

Notes: * - *Scientifically inaccurate;* ** - *Verification lesson;* [a]Studied astronomy in high school or college. [b]Members of this trio had different coherence measures because the group wrote their first lesson together, followed by two lessons written by Melanie, then the group was split and the last two lessons were written by Mandy and Mica separately.