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RESEARCH ARTICLE

Assessing preservice elementary teachers' enactment of science practices using children's astronomy storybooks

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Abstract

Purposefully-designed, science content courses have the potential to help prepare future elementary teachers by helping to develop their understanding of the practices of science. We extend research on how science content courses can prepare future elementary teachers by investigating how students' experiences in such a course contributes to their ability to enact coherent use of science practices within a science investigation. We investigated U.S. college students' enactment of coherent science inquiry investigations after completing an inquiry-based astronomy course designed for preservice elementary teachers. We assessed preservice teachers' (N=63) enactment of the coherence between question, data gathering, and evidence-based explanations using a novel format: student-generated astronomy-based children's storybooks. Most students (59%) wrote storybooks featuring coherent investigations; in other words, their stories featured characters who linked an investigation question to data collection and to an evidence-based explanation. Over the three years of data collection, the percentage of preservice teachers who wrote coherent investigations in their final storybooks increased from 35% to 71% suggesting that additional scaffolding provided by the faculty in years 2 and 3 helped students understand these practices. Our findings suggest that purposefully-designed, science content courses can help preservice teachers learn about coherent science inquiry in astronomy. We also suggest that projects tied to the students' own future careers, such as creating children's science storybooks, can be used as assessment tools by faculty to assess preservice teachers' development of science practices.

Keywords: Science practices; Preservice teachers; Storybooks

1 Introduction

The *Next Generation Science Standards* (NGSS Lead States, 2013) have raised the bar for what is expected of preservice elementary teachers in the U.S. as they begin their careers teaching science to young children. The current reform-based approach to teaching science is likely to challenge new elementary teachers in the complex ways it represents science practices (McNeill et al., 2017); their own K-12 experiences, as well as experiences in college science classrooms, frequently present science in a more fragmented, fact-oriented view, rather than one that embraces questions, evidence, and inquiry (National Research

Council, 2012; Roth and Garnier, 2007). Yet, university-level science courses designed to support this reform-based perspective can make a difference in preparing new elementary teachers for future science teaching (Avraamidou and Zembal-Saul, 2010; Haefner and Zembal-Saul, 2004). This study investigated one such university science course for preservice elementary teachers and how a novel assessment opportunity—writing a children's storybook—might provide insights into these future teachers' understanding of science practices.

2 Conceptual Framework: Coherent Science Inquiry Investigations

Our research highlights the importance of preservice teachers' developing an understanding of science practices. Science practices describe behaviours that scientists engage in as they hypothesize and investigate about the natural world. The science practices framework we draw on is based on the *coherent science inquiry investigation* (CSII)(Plummer and Tanis Ozcelik, 2015), which focuses on the coherence between scientific questions, data gathering, and evidence-based explanations during investigations. Plummer and Tanis Ozcelik Plummer and Tanis Ozcelik adapted the CSII framework from Roth and colleague's *coherent science content storyline* (CSCS) (Roth and Garnier, 2007; Roth et al., 2011). Roth and colleagues recommend that teachers develop lessons that follow CSCS, which involves identifying one main learning goal, communicating that goal to students, selecting activities and representations that reflect that goal, and carefully sequencing activities in ways that build toward that goal. Building on the ways Roth et al. used coherence — an inter-connection between goals and activities to form a whole — the CSII organizes students' consistent use of science practices around the investigation's main goal as the unit of analysis (Plummer and Tanis Ozcelik, 2015). In a CSII experience, students' investigation focuses on making sense of a single phenomenon or related set of phenomena as they construct explanations based on evidence in response to a question or problem about the phenomenon; they may also use other science practices, such as modelling or argumentation, during the investigation in ways that support the development of their explanation. Educators design CSIIs by purposefully choosing and sequencing activities in ways that help students attempt to answer the question by making sense of data to form an evidence-based explanation (Plummer and Tanis Ozcelik, 2015). Focusing on coherence between practices towards developing an evidence-based explanation may allow students to develop deeper understandings of the phenomenon and the use of science practices.

An important component of U.S. preservice teachers' professional development is learning to understand and use the NGSS. The NGSS provides science content standards for the physical sciences, life sciences, earth and space sciences, and engineering and technology; standards describing cross-cutting concepts (core ideas that are relevant within and across the different disciplinary areas); and standards for science practices. These standards were developed to improve science education for students in grades K-12 (ages 5-18) in the U.S. by guiding curriculum and assessment development. Many U.S. preservice teachers will be expected to address these standards in their classrooms in the future. Therefore, we drew on recent frameworks for science practices providing guidance and explanation for the Next Generation Science Standards in the U.S. (National Research Council, 2012; McNeill et al., 2017) and providing specific guidance for teachers working with elementary students in science (McNeill, 2011; Zembal-Saul et al., 2013) to provide additional details to our initial CSII framework in order to clarify our definition of specific science practices used in our study.

Scientists observe and investigate the world towards achieving two goals: "(1) to systematically describe the world and (2) to describe and test theories and explanations of how the world words" (National Research Council, 2012, p. 59). Across all investigations with our students, we emphasized the importance of constructing evidence-based explanations, which "focus on a specific question about a phenomenon and construct a how or why account for that phenomenon" (McNeill et al., 2017, p. 207). As our course was designed primarily for preservice elementary teachers, we began with helping them learn to make careful observations that can lead to identifying patterns that need to be explained or further questions to be explored (Zembal-Saul et al., 2013). Thus, students were encouraged to engage in investigations that generated data both relevant to their question and sufficient to support the claims being made about the phenomenon (NGSS Lead States, 2013; Windschitl, 2017). The how or why account (i.e., scientific reasoning) in the evidence-based explanations draws on a science model or science principle to construct a causal account. We engaged our students in further investigation to test explanatory models, as this can help deepen their understanding of the theories that explain their observations and extend their understanding of how scientists investigate the world.

3 Supporting Preservice Teachers' Understanding and Enactment of Science Practices

To support elementary students' conceptual understanding of natural phenomena, elementary teachers need to be prepared to support students in constructing evidence-based explanations during instruction (McNeill, 2011; Zangori and Forbes, 2013). Studies in teacher education indicate that specially designed content courses for preservice elementary teachers may help them develop this understanding of science practices. These courses are designed to prepare teachers for teaching with science practices by engaging them in content investigations that bring particular science practices to the forefront of the discussion (Haefner and Zembal-Saul, 2004). In other words, by considering a sociocultural perspective on learning (Vygotsky, 1986) and a model of learning science practices that is developed through extended teacher participation in learning moments by using those practices (Ford, 2008), preservice teachers are hypothesized to develop a more integrated knowledge of science and science practices, for the purpose of their future teaching, through their own personal actions of engaging in scientific inquiry with their peers.

Studies with preservice and new elementary teachers provide some insight into how a purposefully designed course for preservice teachers might support their development of teaching practices. Haefner and Zembal-Saul (2004) investigated an innovative science content course designed to engage preservice elementary teachers in science inquiry. Through participation in the course, the preservice teachers' views of science shifted towards one that emphasized scientific process over product as they developed an increased understanding of the experimental aspects of science. Further, after participation in the course the participants "became more accepting of approaches to teaching science that encourage children to investigate phenomena about which they have questions" (p. 1670). Avraamidou and Zembal-Saul (2010) investigated two first year teachers' use of science practices with students in their classrooms. As undergraduates, one of the teachers had taken three courses specifically designed to support preservice teachers' understanding of the practices of science; the other had only taken traditional science courses. The teacher who had taken the specially designed science course engaged her students in the language of constructing and communicating claims through inquiry-based investigations while the other new teacher used limited scientific discourse in her classroom. Drawing on evidence from interviews that highlight coherence between the teachers' knowledge of science teaching practices and beliefs about what experiences shaped their teaching, Avraamidou and Zembal-Saul point to the important role played by the purposefully designed content courses in shaping the first teacher's practice. Zangori and Forbes (2013) also emphasized the importance of attending to preservice teachers' own understanding and enactment of science practices as this will shape how they engage students in the future. Using multiple case study design, they found that elementary preservice teachers who had difficulty conceptualizing their own ideas about constructing evidence-based explanations struggled to support their students in this practice.

Research on college-level astronomy courses provides additional insight into how a science content course designed around science practices might help develop preservice elementary teachers' understanding of science practices. Plummer and Tanis Ozcelik (2015) studied preservice teachers who engaged in an extended astronomy investigation that scaffolded students' participation in collaborative sense-making around modelling and evidence-based explanations, as part of their science methods course. Preservice teachers who developed CSIIs in their lesson plans included more complex sense-making practices (i.e., evidence-based explanations and generating representations) than preservice teachers who did not develop for CSIIs in their lessons. Plummer and Tanis Ozcelik also found that preservice teachers with higher astronomy content scores were more likely to develop coherent science investigations in the lesson plans they wrote than students with lower scores. Slater, Slater, and Shaner (2008) investigated a course for preservice elementary teachers where students learned astronomy through *backwards-faded scaffolding* investigations: removing supports to shift towards open-ended inquiry over the course of the semester. After taking the course, students showed significant improvement in their understanding of both science practices and the astronomy content. Further research has also found that non-science majors improve their understanding of inquiry after taking an introductory astronomy course using backwards-faded scaffolding investigations (Lyons, 2011; Sibbernsen, 2014). However, another study using the same curriculum materials and the same research instrument in an introductory astronomy course found no improvement (Stewart, 2013). Stewart's study suggests that the nature of the guided experience—how the instructor engages the students in discourse around the investigations—is critical to shaping learners' knowledge of when and how to use science practices.

Taken together, these studies suggest university science courses may play an important role in preparing preservice teachers to engage in science discourse and enact science practices, in preparation for their future teaching (Haefner and Zembal-Saul, 2004; Lyons, 2011; Plummer and Tanis Ozcelik, 2015; Sibbernsen, 2014; Slater et al., 2008). College science courses that emphasize engagement in the practices of science and that scaffold preservice teachers' experiences over time have the opportunity to develop preservice teachers' understanding of science practices, which in turn may shape how they are prepared to cultivate their future elementary students' understanding of science phenomena (Avraamidou and Zembal-Saul, 2010; Zangori and Forbes, 2013).

4 Science Curriculum and Children's Science Storybooks

Our study considered how we can further preservice teachers' education by facilitating their engagement with curriculum materials as we investigated their development of storybooks as a form of curriculum design. Curriculum materials serve as tools to mediate a teacher's planning and enactment in the classroom (Brown, 2009; Forbes, 2011). Teachers need curriculum materials to be accurate with coherent contents, have clear purpose for learning, and provide multiple opportunities for students to represent their ideas (Davis and Krajcik, 2005). However, while elementary teachers often use curriculum materials for their science instruction, they rarely have an opportunity to write their own curriculum materials (Forbes, 2011).

Children's science storybooks are an important classroom resource and could be useful tools to support young learners in engaging with science practices (Plummer and Cho, 2020; Pringle and Lamme, 2005). Murmann and Avraamadou (2014) investigated the use of stories as learning tools for elementary students during an inquiry-based investigation. They found that while the stories have significant potential, their use as a tool for science inquiry is dependent on the teacher's understanding and beliefs about science teaching and learning. This suggested to us that helping our preservice teachers write storybooks that include CSIIs could be an important step towards their own development as teachers who plan to use stories as tools for inquiry. We asked the preservice teachers in our course to write a children's storybook within the domain of astronomy—the focus of our course—that included a character or characters participating in an investigation that concludes with constructing an evidence-based explanation. This type of children's storybook is similar to a *dual-purpose storybook* which not only includes an entertaining, character-driven narrative but also conveys factual science content (Donovan and Smolkin, 2002). While typical dual-purpose children's storybooks present factual information through insets or diagrams, we encouraged students to integrate science content and practices directly through their storybook's narrative. Similar dual-purpose storybooks have been used to support preschool-age children in constructing evidence-based explanations by communicating questions or problems that connect to investigations of scientific phenomena (Plummer and Cho, 2020). Thus, engaging preservice teachers with this storybook format could provide them with a potentially useful pedagogical tool in their future teaching.

The storybooks also served as a novel method to assess our preservice teachers' enactment of science as a process of constructing explanations from evidence through coherent science inquiry investigations. Students needed to take what they learned in our course about astronomy and coherent science inquiry investigations and apply that to writing their storybook. Our study was guided by the following research question: *In what ways do dual-purpose storybooks, written by preservice elementary teachers at the end of an astronomy content course, demonstrate an ability to enact coherent investigations that lead to evidence-based explanations in astronomy?*

5 Methods

5.1 Context of the course

The research subjects were drawn from three separate offerings of an astronomy content course designed specifically for pre-service elementary teachers at a large research university in North-eastern U.S. The course was co-taught by two authors of the present study - faculty in an education department and an astronomy department. The course is organized using a coherent science content storyline format (Roth and Garnier, 2007; Roth et al., 2011) by sequencing investigations towards one main learning goal: gathering evidence in support of Solar System formation as the underlying causal model explaining patterns observed among Solar System objects. We communicated this to the students and carefully selected investigations that built students' understanding towards the larger goal. The course met twice a week for 75 minutes each session; nearly all of the time was dedicated to work on the investigations with very little time spent that would be considered lecture-based. In-class investigations, science notebook assignments, and science report assignments emphasized the coherence of a science inquiry investigation and allowed students to practice writing about connections between a scientific question, data collection methods, and constructing evidence-based explanations. These experiences culminated with students applying what they learned about coherent inquiry investigations in astronomy towards the final assignment, writing a children's science storybooks.

The students worked in small groups to complete a series of seven investigations, called "storyline activities", that address smaller pieces of the storyline (see Table 1). Storyline activities were either guided inquiry (question, background, and procedures provided) or open inquiry (question and background provided) (Buck et al., 2008). In each in-class storyline activity, the instructors provided investigation questions to guide students' engagement in the process of planning their investigation, gathering data, and co-constructing an evidence-based explanation (Zembal-Saul et al., 2013). Students worked collaboratively to investigate astronomy phenomena by collecting data, generating claims, and developing reasoning. Students then participated in whole-class discussions which functioned as a way for small groups to share ideas, critique other groups, and receive feedback from professors and peers on their use of science practices. Students kept daily records throughout the investigations using electronic science notebooks with the web-based software *Evernote*.

Students wrote reports based on three storyline activities (the phases of the Moon, how and why planets orbit the Sun, and the properties of the planets). In the reports, the students summarized their investigation methods, discussed their findings, and included their evidence-based explanations in response to the investigation question provided in class. Though reports were individually written, the students developed their ideas and arguments through collaboration with their small group and whole-class discussions. Professors provided detailed feedback on each student's report to help them improve their understanding of how to communicate the results of a coherent science inquiry investigation.

The storybook assignment was introduced about 8 weeks into the semester. Requirements for the storybooks, as described in the Storybook Assignment Sheet, are included in Table 2. First, the students turned in a short outline that included an investigation question, a description of how the investigation will be carried out in story format, and a description of the final explanation. Each student received written feedback from one of the instructors on their outlines. Near the end of the semester, students were asked to bring a nearly completed version of their books to class for a guided peer review. Using the final grading rubric as a guide, pairs of students provided each other with feedback about the scientific accuracy of the story, the coherence of the investigation, and how their use of images communicated important information about their storybook investigation. Students were able to ask the instructors for additional assistance with the assignment. Final storybooks were submitted in an electronic format to the instructors at the end of the semester. See Figure 1 for example pages from three student storybooks.

5.2 Participants

A total of 67 students were enrolled in the course across the three years of data collection (2015-2017). Almost all students were in their first or second year of college, and had indicated their intent to pursue an elementary education major leading to certification to teach pre-Kindergarten to 4th grade (age 3-11 years). We also collected data from one student pursuing a grade 4-8 certification, one student pursuing secondary education world language certification, one student nearly done with completing her pre-Kindergarten to 4th grade degree, and

Table 1. Storyline activities building towards the formation model of the Solar System

	Storyline activity topic	Investigation questions	Approx. Length
1	Naked-eye astronomy	How and why does the appearance of the Moon change over time? How does light pollution affect our observations of the stars we observe in the night sky? How does the Sun appear to move and why?	3 weeks
2	Finding planets	Where do we find planets in the sky and how can we use this to predict future planet observations?	2 weeks
3	Investigating orbits	What factors are needed to produce a stable orbit similar to the orbits of planets in our Solar System?	2 weeks
4	How astronomers collect data	What methods can astronomers use to investigate the objects in the Solar System as well as distant stars and why?	2 weeks
5	Craters and the history of the solar system	Do all planet and moon surfaces in the Solar System show the same effects of crater-making impacts from the Late Heavy Bombardment period and why?	2 weeks
6	Solar system properties	How can the planets be grouped according to their properties?	2.5 weeks
7	Formation of the solar system	How does the model of the Solar System's formation explain patterns we observe in the current Solar System?	1.5 weeks

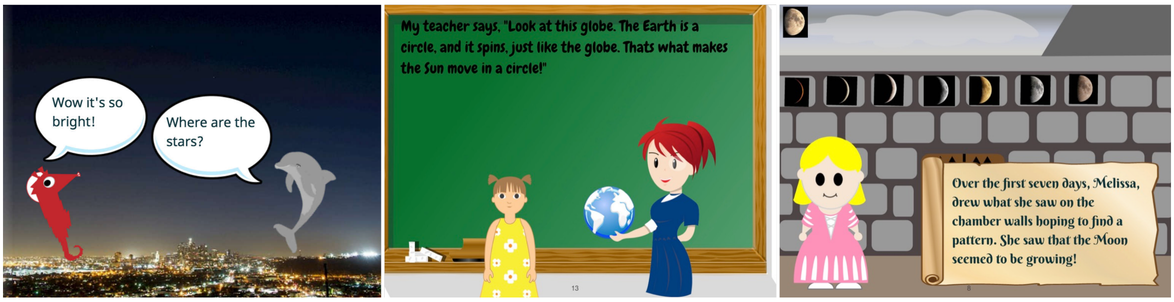

Figure 1. Example storybook pages from "Dolphie and the Stars" by Diane, "Sola and the Sun" by Bethany, and "The Moon Girl" by Ellen.

Table 2. Requirements for Children's Storybook as given in the Storybook Assignment Sheet

Book must contain a creative element that distinguishes this as a children's book as opposed to dry presentation of science fact.
Must include science content but may include a fictional story element (e.g., such as including characters in fictional situations).
Book must be centred around a *Solar System astronomy investigation* but does not have to be one of the specific investigations we did in this class. • Include an investigation question or questions. • Use the story to either encourage the reader to carry out an investigation or show characters in the story carrying out an investigation that answers the investigation question(s). • Demonstrate through your storybook that you are understanding how evidence is used to answer scientific questions. • Demonstrate appropriate methods of collecting data for the astronomy investigation in your storybook. • Integrate into the story the evidence-based explanation that answers the investigation question(s) posed. • Communicate how the reasoning would be constructed for that evidence-based explanation, which may include discussing an appropriate scientific model.
Presentation of the book should reflect elements of a children's book, including the use of photos and/or images that support the narrative, as opposed to an essay or report. • Must include a list of references to ALL images used at the end of the book. • If you want to share this book more broadly in the future, we recommend using public domain images, where possible. Public domain images include those from NASA and Wikimedia Commons.
Book must demonstrate accurate understandings of the science content.
Include a glossary of astronomy terms used, at the end of the book.

one engineering student who did not intend to pursue a teaching certification. Most of the students in the study were female (92%). At the beginning of each semester, students were asked to indicate their willingness to provide their assignments (including storybooks) for this study. All students provided this level of consent for the project. All student names in this manuscript are pseudonyms.

5.3 Data collection

We analysed the final electronic storybooks (N=63) submitted at the end of the semester (some sample attrition occurred due to digital file loss and one student who did not complete the assignment). The number of storybooks gathered for analysis per year was: n=17 in Year 1, n=22 in Year 2, and n=24 in Year 3. The average length of a storybook was 22 pages (SD=8.7) (no length requirement was given in the assignment).

5.4 Analysis

We developed a coding scheme by defining categories based on key elements of the CSIIs represented in the storybooks: use of *investigation questions, planning and carrying out investigations, and constructing explanations* (Table 3). Initially, codes were defined using literature describing these science practices (*e.g.* McNeill et al. 2017; National Research Council 2012; Windschitl 2017; Zembal-Saul et al. 2013). The first round of coding by two co-authors led to additional generations of codes specific to the storybooks in our sample. Subsequent rounds of inter-rater reliability (IRR) coding further refined our coding document. After two rounds of IRR, two coders reached >90% agreement in *investigation questions and planning* and *carrying out investigations* categories. After three rounds of IRR, the same two coders reached 71% agreement on the *evidence-based explanation* codes. Discussion of disagreements improved the coding document and the remaining storybooks were checked by the team to reach 100% agreement on *evidence-based explanations*, improving reliability for this category.

We analysed the data by generating descriptive statistics for categories and codes to look for themes in how students used science practices in their storybooks. We also created a new category, using existing codes, to identify storybooks that presented coherent investigations (Plummer and Tanis Ozcelik, 2015). A coherent investigation included an investigation question, sufficient data, and a claim based on evidence (with or without reasoning). Further, our definitions for each of these codes include the requirements that data are relevant to the investigation question and the claim is in response to the question, resulting in a coherent investigation.

6 Findings

We begin with presenting themes in how students included key science practices (investigation questions, planning and carrying out investigations, constructing explanations) in their storybooks. We conclude with a discussion of students' use of coherent science inquiry investigations. Overall, we found that while the majority of students were able to plan coherent investigations in their storybooks, other students' storybooks were missing key elements of a coherent investigation. However, this improved over the three years we taught the course.

Table 3. Science practices codebook for analysis

Categories	**Codes**	**Definitions**
Investigation Questions	Descriptive question	Characters pose a question about descriptive qualities of a phenomenon (e.g., a "what does it look like" or "how long will it take" question).
	Causal question	Characters pose a question that asks for a causal mechanism for a phenomenon (e.g., "why did that happen").
Planning and carrying out investigations	Sufficient data gathered	Characters gathered a large enough data set to answer their investigation question. Data must be relevant to the investigation question.
	Insufficient data gathered	Characters gathered data, but the dataset was not large enough to support their claims
	Relevant data gathered	Characters gather data that will actually be useful to answer their questions.
	Data gathered, but irrelevant to question	Characters gather data, but data cannot be used to answer investigation question
	Plan is discussed to gather data	Characters explicitly discuss an observation plan before carrying it out. When coding, specify which of the characters is coming up with the plan.
Constructing explanations	Claim not supported by evidence (no reasoning)	Characters present a claim without discussing the evidence or reasoning supporting the claim.
	Claim supported by evidence with no reasoning	Characters have a claim that is supported by their evidence, but do not use scientific concepts to reason through why their evidence supports their claim. This also applies when descriptive questions that do not require reasoning (even if it is provided) are asked.
	Claim based on evidence supported by reasoning	A claim is presented that is supported by evidence. The character also uses scientific ideas and theories to develop a connection between their claim and evidence. This reasoning can be considered an attempt rather than rigorous use of theory/model to support claim and evidence.
	Claim presented with reasoning, but no evidence	A claim is presented without a discussion of the evidence behind it. The character presents scientific ideas and theories to support their claim.
	Claim not coherently matched to evidence or reasoning	A claim is made, but not supported by evidence or reasoning. The evidence and/or reasoning is there, but it does not support the claim (e.g., not aligned to the claim).
Development of reasoning	Main character involved in developing model	The main character develops an explanatory model as part of their explanation (claims, evidence, or reasoning). A model is a sense-making tool that can be used to predict and explain. Can be physical, represented in the story in a character's thoughts, or through character dialogue.
	Main character describes but does not develop model	Main character presents a model of the observed phenomenon but does not provide any indication of where the model came from.
	Model developed by someone else in story	Another character/authority figure develops a model for the main character.

6.1 Topics and question types

Students were instructed to write their storybooks "centered around a Solar System astronomy investigation but [it] does not have to be one of the specific investigations we did in this class" (*Storybook Assignment Sheet*). And while the students often did not follow the exact questions or procedures in their storybooks that the class used when conducting investigations, all topics the students chose were based on investigations we engaged with during the semester. The majority of the students wrote a story investigating the phases of the moon (n=37, 59%). The next most frequent topics were the motion of the Sun, the planets, or the constellations in the Earth's sky (n=11, n=17%), physical properties of the planets (n=6, 9%), craters on solid worlds (n=4, 6%), and light pollution (n=4, 6%). One additional student wrote a story asking how astronomers collect data.

We further analysed whether students posed descriptive questions or causal questions. A descriptive question might seek to describe a pattern in a phenomenon, such as the question in Courtney's storybook: "How long will it take for the Moon to complete its full cycle and go back to its full self?" Nearly a third of the students posed descriptive questions in their storybooks (n=20, 32%). A causal question goes beyond a description to ask about the underlying cause of the observations or pattern in the phenomenon. For example, Mindy's story asks "I wonder why the Moon looks different on different days?" Most students posed causal questions (n=37, 59%). Students were strongly encouraged, through written instructions, in-class discussion about the assignment, and peer review, to write stories that included reasoning in their evidence-based explanations. Providing reasoning suggests that the character investigating the phenomenon is responding to a causal question. Finally, even though students received feedback on a story outline, six students (10%) did not pose an investigation question in their final storybook.

6.2 Planning and carrying out investigations

We also considered how the students provided opportunities for the character to gather data that was both relevant to their investigation question and sufficient for answering that question. The majority of students (n=50, 79%) included relevant data gathered for their investigation. Further, most of the students (n=39, 62%) were also coded as having shown the character gathering sufficient data to answer their investigation question. For example, Diane's storybook "Dolphie and the Stars" follows a dolphin as she answers a question about light pollution, "Why do the stars look different in the sky?" Throughout the story, Dolphie makes observations in several locations including near a large city, near a factory putting out smoke, in a remote area away from cities, and during cloudy weather. Her observations are both relevant and sufficient to support a general claim about why we see different brightnesses or densities of stars in different locations. In contrast, Kaitlyn's storybook, "Max and the Moon," included relevant but insufficient data to answer the investigation question: "How many days are in a Moon's cycle?" The character makes observations of the Moon and records these in his science journal; however, he only observes for 16 days before concluding that the moon's cycle takes one month. The character made an error we frequently observed in both the students' storybooks about the lunar phases and their earlier reports about the lunar phases: they provided only half of a cycle's worth of data but attempted to infer the entire length of the cycle rather than providing sufficient data to support the claim. Only three students' storybooks did not describe a process of data collection. Thus, a majority of the students demonstrated an understanding of the necessity of gathering sufficient, relevant data as important for a scientific investigation—as told through the format of a children's storybook.

6.3 Constructing explanations

Nearly half of the students (n=30, 48%) included a claim supported by both evidence and reasoning developed by one or more characters in the story. For example, in Bethany's story "Sola and the Sun" a young girl, Sola, notices the change in the Sun's location in the sky after painting it at sunrise and sunset. After her father suggests that she investigate her question "How does the Sun appear to move during the day?," Sola uses a compass to track the Sun and paint its location throughout the day (see Figure 2). She uses this evidence to construct a claim: "Look Dad the Sun looks like it moves in a circle! Look how high it was at lunchtime!"

To construct her reasoning, Sola asks her teacher, who tells her to look at a globe to show how the Earth's spinning is "what makes the Sun move in a circle." And while Sola builds on this model for her reasoning, elaborating the explanation for her father, the main character initially relied on outside experts to construct the reasoning. This use of an expert to provide the scientific reasoning in the explanation was relatively common among the preservice teachers (n=27, 43%); fewer storybooks included main characters developing the reasoning for themselves (n=11, 17%). Our goal was for the students to write stories in which the main characters took ownership in developing the reasoning for their explanations as this would provide the reader with a more sophisticated view of modelling practices and scientific reasoning than if an expert were to just tell the main character the reasoning piece as a fait accompli. Therefore, in class, we encouraged students to write stories where the main character collaboratively developed the scientific reasoning, possibly in with a more knowledgeable other or with other characters of similar knowledge level. However, most of our students are likely to have experienced a traditional form of science education where, even if they performed investigations to collect and analyse data, the teacher presented them with the completed scientific model and explained the reasoning for them. In our course, we worked with students, guiding them to develop scientific models they could use to explain their observations. Thus, for many students, our course may be one of the first opportunities to learn science by developing their own scientific models—an important feature of the *NGSS* (McNeill et al., 2017).

An additional 12 students (19%) included a claim supported by evidence without the inclusion of reasoning. For example, in Abby's storybook "Finn's Journey of Finding the Moon," a young turtle, Finn, notices the Moon in the sky appearing to get larger on subsequent nights. He decides to make observations of the Moon to answer his question "How does the appearance of the Moon change?" (descriptive question). Each night, Finn drew pictures of the Moon and began to notice the Moon becoming bigger, until after the 15th night, it started to become smaller.

Figure 2. Image from Bethany's storybook showing a record of her evidence (the location of the Sun throughout the day) to support her claim in the text. She uses the Earth's rotation as reasoning to make sense of how her evidence supports her claim.

On the 31st night, he noticed that the Moon appeared as it did on his first observation. Finally, Finn analyses his observations in order to state a claim: "I realized that in a 30 day cycle, the Moon goes through different phases that cause the appearance to change. After this 30 day cycle, the cycle repeats." Abby shows how Finn used careful observation to figure out the cycle of the phase of the Moon, but concluded her storybook without her character providing reasoning for the explanation.

Students who included a claim supported by evidence without reasoning in their storybooks often posed descriptive questions about the qualities of a phenomenon such as "Are Jupiter and the other planets like our planet, Earth?" (Leah's storybook). It may be that due to the nature of their descriptive investigation questions, their explanations in storybooks did not include reasoning. However, when combined with the students that also included reasoning in their explanations, we found that about two-thirds of our participants (67%) demonstrated how evidence-based claims are important aspects of a scientific investigation through the storybook medium.

6.4 Developing a coherent science inquiry investigation across a storybook

Our primary goal throughout the semester was supporting students' ability to communicate their investigations as coherent narratives, from investigation questions through evidence-based explanations. We identified those storybooks which included CSII: using a story to connect an investigation question, with relevant and sufficient data to answer that question, and constructed a claim based on evidence (with or without reasoning). For example, Ellen wrote a creative story that includes a CSII in her storybook, "The Moon Girl." In her story, a King has a playground which he has forbidden his citizens from entering. The main character, Melissa, plays on his playground, is caught, and is locked in a tower. She will not be let out until she figures out the phases of the Moon and is instructed to "determine how and why the phases of the Moon appear to change or look different over time?" (causal investigation question). To record her data, Melissa drew pictures of the Moon on the wall each day for a month (sufficient data). Over time, she began to notice a pattern in her observations as the Moon began to grow to Full and then decrease back to new (claim based on evidence). Yet, once she figured out the pattern, the King told her she must figure out why this happens, before she can be released. With some guidance from the King's son, Melissa realizes that it is the Sun that illuminates the Moon and that its appearance changes as it orbits the Earth (model-based reasoning). She is released and allowed to play on the playground for the rest of her life.

The majority of students (n=37, 59%) wrote stories featuring CSII, thus enacting how a scientific question can be used to determine what evidence is relevant and sufficient to answer a question, and use that evidence to construct a claim. Further, this percentage improved over time: Year 1, 6 students (35%); Year 2, 14 students (64%); Year 3, 17 students (71%). This suggests that we, the faculty teaching the course, gained insight into ways to further support the students after the first year of the course to better scaffold their understanding of coherent investigations.

7 Conclusions and Recommendations

Our findings demonstrate that, after participating in the "Astronomy for Educators" course, the majority of the preservice teachers were able to enact science practices that led to a coherent, astronomy-based investigation, through the medium of a dual-purpose children's storybook. This supports previous findings that suggest purposefully designed content courses for preservice elementary teachers can play a role in supporting their development towards understanding science as an evidence-based process of explaining phenomena (Avraamidou and Zembal-Saul, 2010; Haefner and Zembal-Saul, 2004). While we were not able to follow these preservice teachers into their first experiences teaching science to elementary students, this provides some evidence that they may enact a use of these science practices in future lesson planning. Prior research indicates that increased domain-specific knowledge influences the level of coherence in inquiry-based lessons produced by future teachers (Plummer and Tanis Ozcelik, 2015). Thus, one useful feature of this course could be how we first supported the preservice teachers' in developing domain-specific knowledge alongside the ways they learned to enact the practices of science. Developing their knowledge may have helped them make sense of coherent astronomy investigations which they represented in curriculum material through dual-purpose children's storybooks.

Yet, a large percentage of students (41%) did not write coherent investigations in their storybooks. Throughout the semester, some students struggled to make connections between asking a scientific question, providing sufficient data, and using this to generate evidence-based claims. This may have continued through into their attempts to write an investigation in storybook form. In addition, some students may have had difficulty translating a new or limited understanding of science practices into a novel format: children's storybooks. However, our students' performance in writing storybooks with coherent investigations improved from 35% in Year 1 to 71% in Year 3. This suggests that over time, we (the faculty teaching the course) improved the ways we engaged our students in coherent scientific investigations, through their participation in a content course designed around a coherent science content storyline. Across each year of the course, instructors supported students through multiple investigations, rounds of sharing in small-group and whole-class conversations, and three reports that used a scientific (rather than creative) format for expressing this same idea of a coherent investigation. Specific improvements made between the Year 1 and 3 included: providing an example report that illustrated how to write about a coherent investigation, increasing how frequently we prompted students to make explicit connections during ongoing class investigations and presentations, providing additional explicit examples of our own of the connections between question, data collection, and explanation throughout the semester, and improving our own understanding and insight into the students' difficulties with engaging in science practices which allowed us to provide more timely support and more helpful feedback. These additional prompts and examples were woven throughout the semester which provided students with additional opportunity to practice doing science with their peers. The social nature of learning in our course contributed to how they were able to translate the enactment of science practices into use in storybook form (Ford, 2008; Vygotsky, 1986).

One of the challenges students had in creating coherent science inquiry investigations was in generating an investigation question for their storybook, even with guidance provided by the instructors. Prior research suggests that the creation of research questions is often the most difficult stage of a scientific investigation for students (Slater et al., 2008). Further, while students in our course were provided with several examples of investigation questions, they did not practice generating investigation questions as part of their in-class investigations. This finding suggests that preservice elementary teachers may need more practice generating investigation questions for coherent inquiry investigation. One limitation was that we did not explicitly teach the students the difference between descriptive and causal questions. More explicit instruction and opportunities to practice generating and using each kind, such as generating a story for both a descriptive and causal investigation, may have helped students understand why each type of investigation is important to science.

Another challenge students had, in generating coherent investigations in their storybooks, was to provide sufficient evidence to support their claim. Most of the problems in students' use of sufficient evidence occurred in storybooks relating to the lunar phases (the most frequent topic) where students included data for half the cycle or less. Students may not have understood how the Moon's cycle was determined from the observations or may have felt that an observer is justified in making a claim that infers the pattern from a limited data. This suggests students may have needed experience with the practice of rebuttal in which students debate which alternative claims best fit the existing evidence (Zembal-Saul et al., 2013). Such an approach could help them appreciate why additional data is needed as evidence to support their claims about the length of the Moon's cycle and to rule out alternative explanations.

And while many students included a claim supported by evidence in their storybooks, fewer provided reasoning that drew on a scientific model or science principle to explain why the phenomena occurred. For some of these students, their choice of descriptive investigation questions may have led to explanations without reasoning. Similar to prior research with middle (McNeill and Krajcik, 2007; McNeill et al., 2006) and high school students (McNeill and Pimentel, 2010), our students found the use of scientific reasoning to be more challenging than providing evidence for their claims. Science courses for preservice teachers may need to support preservice teachers to understand the importance of developing causal questions as a step towards understanding the development of reasoning in evidence-based explanations. In addition, providing opportunities for students to develop hypotheses based on science principles as part of the investigation process may help deepen their understanding of how reasoning is used to construct evidence-based explanations.

Based on our findings, we recommend that other universities offer content courses for preservice teachers that engage them in multiple cycles of coherent inquiry investigation to support their understanding of content and enactment of science practices. We designed this course for preservice teachers to provide multiple opportunities for their engagement in coherent inquiry investigations across the course in astronomical concepts through ongoing classroom collaboration. The scaffolding we offered across the course is consistent with previous studies of astronomy courses that demonstrate how specific guidance significantly supports college students' understandings and science practices (Lyons, 2011; Sibbernsen, 2014; Slater et al., 2008). Our results build on and extend these earlier findings by showing how such a purposefully designed course with multiple cycles of experience to engage in inquiry investigation may lead to a deeper ability to enact science practice, i.e., coherent science inquiry investigations. Explicit in the enactment of these cycles are repeated opportunities to discuss the use of evidence, generation of claims, and application of reasoning among their peers; these practices are key elements to learning in sociocultural theory (Vygotsky, 1986) (Vygotsky, 1998) and reflect how science is learned through the enactment of practices (Ford, 2008).

We also found that a novel assessment format—writing a children's storybook—can be used to assess preservice teachers' ability to enact science practices. Using this assessment, we found evidence of preservice teachers applying knowledge of coherent inquiry investigations to their science stories. This finding provides support to arguments (Murmann and Avraamidou, 2014; Plummer and Cho, 2020; Pringle and Lamme, 2005) about the value of stories as useful learning tools in various learning contexts. We recommend using stories and storybooks as a creative way of assessing student learning. In addition, this novel assessment has the potential to support preservice teachers' future careers in that they can use this form of assessment with their future students.

8 Limitations and Future Research

One limitation of our study is that we did not have an opportunity to measure our students' enactment of science practices at the beginning of the semester in a way comparable to our measurement using the storybook format. This limits the extent to which we can make claims about their growth across the semester. In future iterations of this study, we might consider our research design to capture participants' prior knowledge and abilities in order to track development throughout the course in order to better understand the effects of our intervention in supporting preservice teachers' development of their own curriculum materials. In addition, we are limited in our understanding of what the students learned about astronomy during this course and how their astronomy knowledge influenced their topic choice or their development of science storybooks. We might find that preservice teachers who made greater content gains were more likely to have coherent investigations in their storybooks. This aligns with Plummer and Tanis Ozcelik (2015) who found that preservice teachers who better understood astronomy developed more coherent inquiry investigations. Future research could investigate how preservice teachers' content knowledge may be correlated with the quality of their storybooks.

We also did not include follow-up research on how the preservice teachers use their storybooks as curriculum materials in their teaching to support students' science practices and science inquiry. Avraamidou and Zembal-Saul (2010) illustrate how early-career elementary teachers from the same teacher education program who took different kinds of coursework (typical college lecture-based science courses versus science courses specifically designed for prospective elementary teachers) taught science differently in their first year of teaching. A preservice teacher who took specially designed, inquiry-based science courses in her teacher preparation program was able to modify the curriculum materials for her students and emphasize the discourse of scientific inquiry through investigation. Avvraamidou and Zembal-Saul's study suggests that the inquiry-based preparation our students received may affect choices they make in the beginning of their elementary science teaching careers. Future research could investigate how preservice teachers use curriculum materials they have authored, such as storybooks, to facilitate coherent investigations during field-work experiences. Future research might also consider how experience writing a science inquiry-oriented storybook might shape preservice teacher's choices in curriculum design or storybook choice in their first years of teaching.

In this research, our students were asked to write coherent investigations in story form on the same topics as they had learned in the course. We are limited in our understanding of whether students developed an understanding of the features of a CSII, separate from the particular investigations from our course, or if they were just repeating the same or similar investigations within their fictionalized storybook format without fully understanding why they were including each aspect of their investigation. Bamberger and Davis (2013) point to this issue in their study on how 6th-grade students' ability to transfer modelling performance across content areas. They tested their students' modelling performances and conceptual understanding of three content areas: smell, evaporation, and friction. Through model-based instruction, the researchers taught smell and evaporation but not friction. They found that the students improved their modelling performance in all three content areas. Bamberger and Davis found that middle school students' modelling practices can be transferred to a new content area when learned in the context of science practice-based instruction. Future research could conduct a comparison between writing a coherent investigation storybook about a topic learned in the course and writing a coherent investigation storybook about a science topic familiar to students, but that they did not learn during the course. This could provide insight into the extent to which students extracted the nature of a coherent science inquiry investigation from the context of an astronomy investigation.

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