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# Scientific Practices in Elementary Classrooms: Third-Grade Students' Scientific Explanations for Seed Structure and Function

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**ABSTRACT:** Elementary science standards emphasize that students should develop conceptual understanding of the characteristics and life cycles of plants (National Research Council, 2012), yet few studies have focused on early learners' reasoning about seed structure and function. The purpose of this study is twofold: to (a) examine third-grade students' formulation of explanations about seed structure and function within the context of a commercially published science unit and (b) examine their teachers' ideas about and instructional practices to support students' formulation of scientific explanations. Data, collected around a long-term plant investigation, included classroom observations, teacher interviews, and students' written artifacts. Study findings suggest a link between the teachers' ideas about scientific explanations, their instructional scaffolding, and students' written explanations. Teachers who emphasized a single "correct explanation" rarely supported their students' explanation-construction, either through discourse or writing. However, one teacher emphasized the importance of each student generating his/her own explanation and more frequently supported students to do so in the classroom. The evidentiary basis of her students' written explanations was found to be much stronger than those from students in the other two classrooms. Overall, these findings indicate that teachers' conceptions about

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scientific explanations are crucial to their instructional practices, which may in turn impact students' explanation-construction.  *Sci Ed* **98:**614–639, 2014

## INTRODUCTION

Plant growth and development is a foundational scientific concept that spans K-12 curriculum standards (National Research Council [NRC], 2000, 2012). Elementary science standards specifically emphasize that early learners should develop conceptual understanding about characteristics and life cycles of organisms, as well as interactions between organisms and their environment (NRC, 2000, 2012). The focus on plant characteristics and life cycles in the early grades is particularly important because some evidence suggests that as children develop, their ability to notice plants, their assumptions about the importance of plants, and their interest in plants deteriorates (e.g., *plant blindness*, Wandersee & Schussler, 1999). The conceptual understanding students develop about plants in the elementary grades therefore serves as a foundation for later science learning (Duschl, Schweingruber, & Schouse, 2007). Although education research has predominantly focused on students' alternate conceptions about photosynthesis (e.g., Canal, 1999), few studies have focused on early learners' scientific reasoning about plant growth and development (e.g., Beyer & Davis, 2008; Jewel, 2002; Metz, 2008), particularly early learners' understanding of seed structure and function.

Scientific explanation-construction is a crucial scientific practice that helps facilitate students' conceptual development (Duschl et al., 2007; NRC, 2012). It is defined by opportunities for students to connect observable cause and effect with an underlying unseen mechanism (Braaten & Windschitl, 2011; NRC, 2012). While engaging in this process, students are able to address an investigation question empirically and examine their existing knowledge in light of new knowledge (NRC, 2000). A growing literature base has documented elementary students' abilities to engage in explanation-construction (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999; Mason, 2001; Metz, 2008; Ryu & Sandoval, 2012; Zuzovsky & Tamir, 1999). However, for elementary students to formulate scientifically accepted, mechanism-based explanations effectively, scaffolding in multiple forms is required in knowledge-rich learning environments, providing students with opportunities to challenge their preexisting naïve explanations and construct new knowledge (Mason, 2001; Ryu & Sandoval, 2012). Yet, explanation-construction is frequently deemphasized in elementary science learning environments (Forbes, Biggers, & Zangori, 2013; Metz, 2008; Zangori, Forbes, & Biggers, 2013). Like those designed for middle-school and secondary science (Beyer, Delgado, Davis, & Krajcik, 2009; Kesidou & Rosemann, 2002), widely available science curriculum materials used in the elementary classrooms tend to not prioritize opportunities for students to propose a mechanism for observed cause and effect (Biggers, Forbes, & Zangori, 2013; Kuhn, 2009; Metz, 2004; Zangori et al., 2013). Furthermore, some evidence suggests that even when explanation-construction is emphasized in curriculum materials, teachers may not enact them as intended (e.g., Beyer & Davis, 2008; Metz, 2009), a finding consistent with theoretical perspectives on the teacher–curriculum relationship (Davis & Krajcik, 2005; Remillard, 2005).

More work is needed to understand how elementary students can be supported to formulate scientific explanations, particularly about topics such as seed structure and function where students exhibit a variety of alternate conceptions. Here, we examine explanation-construction within the context of a long-term investigation about plants in three third-grade classrooms. We ask the following research questions:

1. How do third-grade students formulate written scientific explanations about seed structure and function?
2. In what ways and why do third-grade teachers provide instructional support for students' formulation of scientific explanations about seed structure and function?

## BACKGROUND AND CONCEPTUAL FRAMEWORK

### Scientific Explanations in the Elementary Classroom

The recently released *Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012) defines scientific explanations as

> ... accounts that link scientific theory with specific observations or phenomena ... they explain observed relationships between variables and describe the mechanisms that support cause and effect inferences about them. (p. 67)

Consistent with this definition, we define a scientific explanation as identification of a *mechanism* that underlies observable *cause* and *effects* or, as Zimmerman (2007) describes, the "process by which a cause can bring about an effect" (p. 184). This perspective on explanation-construction in science aligns with current science education literature (e.g., Braaten & Windschitl, 2011; Duschl et al., 2007) and those within the philosophy of science (Salmon, 1998). Observable causes and effects represent the "what" of natural phenomena, whereas the mechanism is the often unobservable causal force for "how" and "why" a phenomenon occurred, derived from experience in the classroom, that is within the norms of discourse and the production of artifacts (Braaten & Windschitl, 2011; Herrenkohl et al., 1999; Schauble, 1996).

Students, as well as adults, do not develop the capacity for scientific reasoning without frequent sensemaking opportunities and ongoing guidance and support (Herrenkohl et al., 1999; Kuhn, 2009; Ryu & Sandoval, 2012; Schauble, 1996). However, most widely available, off-the-shelf science curriculum materials for kindergarten through third grade are grounded in cognitive developmental theory that assumes early learners are "concrete" thinkers and therefore foreground categorization, classification, and serration of decontextualized science concepts (Metz, 2004). When opportunities for sense making are absent, early learners will draw upon naïve causal mechanisms based on their prior experiences and understandings. These preexisting mechanism "libraries" (Schauble, 1996, p. 112) are frequently different from the scientifically accepted mechanisms, as they are typically developed in the absence of domain-specific knowledge about the phenomenon or after being provided support by an experienced other that can help students notice what they may not see on their own.

The evidence for students' preexisting mechanism libraries is apparent in almost three decades of research on plant growth and development. Alternate conceptions about seed growth and development are prevalent in elementary school (Barman, Stein, McNair, & Barman, 2006; Canal, 1999; Jewel, 2002; Patrick & Tunnicliffe, 2011) and remain into adulthood (Wandersee & Schussler, 1999). Students articulate naïve conceptions about the purpose of the seed, where the seed comes from, what is contained inside the seed, what the dormant seed needs to grow, and whether it is living or nonliving. For example, children do not consider seeds living things until they are planted and watered. This alternative conception may be attributed to children's prior experiences with planting seeds underground. When sprouts appear above ground, the only mechanism available to them is somewhat akin to "magic" as they do not have access to alternative causal mechanism for their observations of seed germination.

When students encounter seed growth and development in the classroom, they may integrate new information into these preexisting explanations, but if the new information is not well understood and connected into a coherent causal story, they may develop a new alternate conception. This new alternate conception may contain *some* elements of the new knowledge, but it will most likely be incorporated into the existing knowledge so that the mechanism will contain elements of naïve understandings attached to scientific principles (Duschl et al., 2007). To provide student opportunities for active sense making (Mason, 2001; Ryu & Sandoval, 2012), there are several epistemic commitments of which scientific explanation-construction should be composed. These include constructing explanations that (a) answer an investigation question, (b) are based on data and evidence that support answering the investigation question, (c) provide opportunities for new understanding; and (d) build on preexisting ideas (Biggers et al., 2013; Forbes et al., 2013; NRC, 2000, 2012; Zangori et al., 2013). When elementary students are provided opportunities to generate scientific explanations in learning environments that have been carefully crafted to address these epistemic commitments, past research has shown that early learners are able to articulate cause, effect, and mechanism for phenomena such as floating and sinking (Hardy, Jonen, Möller, & Stern, 2006; Herrenkohl et al., 1999), force and motion (Hapgood, Magnusson, & Palincsar, 2004), animal behavior (Metz, 2008), and plants (Mason, 2001; Metz, 2008).

## Supporting Students' Explanation-Construction

Recent research suggests that elementary teachers follow their science curriculum materials closely (Biggers et al., 2013; Forbes et al., 2013; Zangori et al., 2013), even though commercially produced curricular tools exhibit a variety of limitations (Beyer et al., 2009; Kesidou & Rosemann, 2002; Metz, 2004, 2008; Patrick & Tunnicliffe, 2011; Schussler, 2008). Specifically for life sciences, topics are fragmented within the science curriculum, making it difficult for students and their teachers to bring together the big ideas with which they engage and/or for teachers to support students in anchoring new knowledge (Metz, 2004; Stern & Rosemann, 2004). While there has been no comprehensive review of elementary science curriculum materials to date (Kesidou & Rosemann, 2002), Schussler (2008) reviewed 69 botanical trade books used frequently in conjunction with elementary curricular units and identified five consistently observed sources of error and omission. These included no mention of fruits or seeds in the plant lifecycle or, if fruits and seeds were included, no explanations for what their function is or how they "appeared" within the life cycle.

To challenge students' alternative conceptions and provide opportunities to develop new explanations, students require scaffolding in multiple forms, both curricular and instructional (Hardy et al., 2006; Herrenkohl et al., 1999). Whole-class and individual discussions in which teachers support students in making observations and discussing competing theories are effective in providing student opportunities in connecting cause, effect, and mechanism and facilitating conceptual change. As Hardy and colleagues (2008) found, as well as others (e.g., Hapgood et al., 2004; Herrenkohl et al., 1999; Mason, 2001; Metz, 2008), the teacher and curriculum working together synergistically (Tabak, 2004) are major factors in effectively designed science learning environments that provide opportunities for generating scientific explanations and foreground conceptual change.

Explanation-construction may take a variety of more student- or teacher-directed forms in the classroom depending on the teacher's knowledge about generating scientific explanations (Beyer & Davis, 2008; Biggers et al., 2013; Forbes et al., 2013; Horwood, 1988; Metz, 2009; Zangori et al., 2013; Zuzovsky & Tamir, 1999). Teachers who locate explanatory authority in the curriculum materials (and see their responsibility as conveying this information to their students) will tend to focus their instruction on providing students with a single "correct explanation" (Zuzovsky & Tamir, 1999 p. 1120). Within this perspective on explanation-construction, there is no need for students to examine alternative explanations. Teachers who see their responsibility as encouraging students to examine explanations for adequacy and evaluate them against other possible explanations use a "structure of science" (Zuzovsky & Tamir, 1999, p. 1120) model. From this perspective, alternative explanations exist; however, the teacher defines her role to support students in evaluating explanations until a satisfactory explanation is constructed. Finally, teachers who support their students to connect cause, effect, and mechanism but consider all explanations valid regardless of their nature or acceptability of the mechanism are characterized by the "self as explainer" model (Zuzovsky & Tamir, 1999, p. 1120). From this perspective, a teacher may make no attempts to support students to evaluate their explanations in light of other explanations.

However, the ways in which different teachers enact the same curriculum materials are dependent on a number of factors, including their knowledge about their students' capabilities, their ideas about scientific explanations, and the ways in which they establish discourse in the classroom (Beyer & Davis, 2008; Biggers et al., 2013; Forbes et al., 2013; Enyedy & Goldberg, 2004; Forbes & Davis, 2010; Metz, 2009; Zangori et al., 2013). These factors affect whether they engage students' in explanation-construction and, if so, how and to what extent. While a research base for elementary students' scientific reasoning exists, little is known about the ways in which elementary teachers use elementary science curriculum materials to provide opportunities for students to construct scientific explanations and the subsequent success students may have in generating mechanism-based explanations, particularly about seed structure and function.

## METHODS

In this concurrent mixed methods study (Creswell & Plano Clark, 2011), we examined how students ($n = 59$) and teachers ($n = 3$) in three 3rd-grade classrooms engaged in explanation-construction during enactment of the 8-week Full Option Science System (FOSS) elementary science unit on plant growth and development titled *Structures of Life* (FOSS, 2005). We used both quantitative and qualitative methods to analyze students' written artifacts. We used qualitative methods to analyze video-recorded classroom observations for evidence of teachers' support for students' formulation of scientific explanations. We used interview data to provide insight into how and why teachers engaged their students in scientific explanation-construction.

### Study Context and Participants

The three elementary teachers in this study—Grace, Emily, and Janet—were participants in a 3-year professional development program designed to support elementary teachers in a large, urban school district to learn to evaluate and adapt newly introduced, kit-based elementary science curriculum materials to better engage students in scientific practices (Biggers et al., 2013; Forbes et al., 2013; Zangori et al., 2012, 2013). The project involved 44 in-service elementary teachers from the partner district as well as four surrounding districts within a single midwestern state. Participation in the project was voluntary, and all participants were compensated for their involvement. Three teachers were purposefully

**TABLE 1**
**Summary Profiles of Study Teachers and Classrooms**

| Demographics | Grace | Emily | Janet |
|---|---|---|---|
| Graduate education | MS in reading literacy | MS in teaching and leadership | None |
| Years of teaching experience | 34 | 16 | 8 |
| School | Eastwood | Eastwood | Northwood |
| Class size | 22 | 20 | 17 |
| Average lesson length (minutes) | 84 | 55 | 57 |

*Note:* Schools and teachers are identified by pseudonyms.

sampled (Creswell & Plano Clark, 2011) for this study because each (a) was a third-grade teacher, (b) taught the FOSS *Structures of Life* unit during the same 3-month period of the school year, (c) was using this curricular unit for only the second time after its adoption by the district, (d) taught in similar school settings, and (e) was in the postinduction phase of her career (see Table 1).

Each of these three teachers reported taking a standard science methods course during his or her undergraduate teacher education program. In addition, each teacher readily participated in district-provided science workshops throughout her tenure in this district. These workshops, led by the district science coordinator, focused on effective uses of science notebooks, the five essential features of inquiry (NRC, 2000), and science content knowledge. Furthermore, Grace and Emily had both taken additional graduate science courses geared for in-service elementary teachers, which included summer research experiences. Grace and Janet also served as the science coordinators for their respective schools during this study.

The FOSS *Structures of Life* curricular unit (FOSS, 2005) focuses on organismal structure and function and is widely used across this midwestern state, as well as nationally. The FOSS curriculum series, developed at the Lawrence Hall of Science, was introduced in 1988 and is used widely in the United States. It has a scope and sequence ranging from kindergarten through eighth grade, covering topics in the life sciences, as well as physical and earth sciences. FOSS curricular units are grounded in Piagetian perspectives on learning, emphasizing cognitive stages of development (Lowery, 1998; Metz, 2004):

> The FOSS program is guided by research on human cognitive development. The activities and intellectual demands are matched to the ways students think at different times in their lives. . . . In their early elementary years, students learn science best from direct experiences in which they observe, describe, sort, and organize objects, organisms, materials, and simple systems. . . . Upper elementary students construct more advanced concepts by classifying, testing, experimenting, and determining cause-and-effect relationships among objects, organisms, and systems. (FOSS, 2005, p. 4)

According to this developmental perspective on learning, K-4 students are at a "concrete" operational level and reasoning abilities have not yet developed (Lowery, 1998). Science experiences for early learners therefore emphasize hands-on experiences where they look for patterns, classify, serrate, and describe their investigations. Research has shown how teachers supplement these materials to provide additional opportunities for scientific sense making (Biggers et al., 2013; Metz, 2004; Ryu & Sandoval, 2012; Zangori et al., 2013).

The first two of the four unit investigations focus on plants. This study occurred during Investigation 1, titled *Origin of Seeds* (Table 2). Students are initially introduced to the

**TABLE 2**
**Overview of FOSS Structure of Life Investigation 1 (Origin of Seeds) Lessons**

| Order Enacted | Location Within Curriculum Materials | Curriculum Investigation Question | Curriculum Description | Curriculum Data Analysis | Curriculum Explanation |
|---|---|---|---|---|---|
| 1[a] | Part 1: Seed search | "Where do seeds come from?"[c] "Where are seeds found on plants?"[c] | Dissection of a bean pod to locate, count, and compare and contrast seeds | Count and graph seeds in a bean pod | N/A |
| 2[b] | Part 1: Seed search | "Where do seeds come from?"[c] "Where are seeds found on plants?"[c] | Dissection of various fruits to locate, count, and compare and contrast seeds | Count and sort seeds from different fruits | None |
| 3 | Part 2: The sprouting seed | "Can a seed grow without soil?"[c] "What effect does water have on seeds?"[c] | Hydroponic investigation of seed growth | Compare and contrast seed changes from seeds not in water to seeds in hydroponic growth environments | "Different kinds of fruits have different kinds and numbers of seeds."[d] |

[a]Lesson 1 ended at the suggested breakpoint within the curriculum materials.
[b]Lesson 2 is the remainder and conclusion of Lesson 1 after the breakpoint.
[c]FOSS (2005, Investigation 1, p. 2).
[d]FOSS (2005, Assessment, p. 6).

phenomena (e.g., fruit) with a short discussion and introduction of new vocabulary terms (e.g., properties). Students then engage in a hands-on investigation including observations, dissection, and data collection. Finally, they classify, organize, and look for patterns and relationships within the data and describe the results of their analysis.

Project teachers participated in a week-long professional development workshop in the summer preceding this study. The workshop focused on all five essential features of inquiry (NRC, 2000), which include opportunities for learners to (a) engage with scientifically oriented questions, (b) give priority to evidence, (c) formulate scientific explanations from collected evidence, (d) evaluate explanations, (e) justify and communicate their scientific explanations. During the workshop, the teachers were provided many opportunities to evaluate elementary science lessons of their own choosing for the ways in which the curriculum materials did, or did not, meet criteria for the feature(s) of inquiry (Zangori et al., 2012). The three teachers in this study utilized time in the workshop to analyze the FOSS *Structures of Life* (2005) unit for features of inquiry and make modifications to unit lessons to address limitations they observed for each feature of inquiry, including explanation-construction. This curriculum planning was in anticipation of enactment of the revised unit in the year in which this study took place.

## Data Collection

The data for this study were gathered during the academic year following the summer workshop. First, each teacher was interviewed eight times over the course of the study using semistructured (Patton, 2001) interviews. A formal interview was conducted both at the beginning and end of the year. It was designed to elicit the teachers' conceptions about scientific explanations as well as the ways scientific explanation-construction should be supported in elementary science learning environments. Six additional interviews occurred immediately prior to and following each lesson enactment. These reflective grounded interviews asked teachers to reflect upon their planned and enacted lessons for ways in which they engaged students in scientific explanation-construction. All interview protocols were explicitly aligned with the theoretical framework underlying this study. All interviews ($n = 24$) were conducted by one of the authors either in person or by telephone, audio-recorded, and transcribed verbatim.

We also conducted live observations of each teacher for each of the three investigation lessons, each of which was video-recorded (three teachers $\times$ three lessons each $=$ nine observations). After each observed lesson, we also collected copies of all artifacts and documents created through whole-class discussion and activity (e.g., smartboard files, class-generated data graphed on easel pads, and other class-generated lists). The whole-class artifacts were collected either as video files or as electronic documents and catalogued.

In the year prior to the study, the school district adopted the use of science notebooks at all elementary grades. All three study teachers began implementing the science notebooks at the beginning of the school year in which the study took place (September). We collected and scanned 177 student science notebooks. Each science notebook entry was assigned a unique identification number that associated the student artifacts with lesson observation number and was catalogued. The collected data were therefore hierarchical, nested per student per teacher, and longitudinal, covering three sequential lesson enactments.

## Data Analysis

***Quantitative Analysis.*** We used the Practices of Science Observation Protocol (P-SOP; Forbes et al., 2013), a recently developed observation protocol for elementary science, to score both the teachers' lesson plans and video-recorded enacted lessons. The P-SOP is grounded in the five features of inquiry (NRC, 2000). One of the features of inquiry the P-SOP is designed to measure is *formulate explanations about phenomenon of interest that answer investigation question*, a core scientific practice in the elementary grades (Beyer & Davis, 2008; Metz, 2008). In the P-SOP, this scientific practice is measured through four epistemic components: Students should formulate explanations that (a) are based on evidence, (b) answer investigation question, (c) propose new understanding, and (d) build on their existing knowledge (NRC, 2000, 2012).

The P-SOP has been found to be a valid and reliable measure of inquiry in elementary science learning environments (Biggers et al., 2013; Forbes et al., 2013; Zangori et al., 2013). In a previous study, interrater reliability was established through joint scoring of 124 video-recorded elementary science lessons. For the feature *formulate explanations about phenomenon of interest that answer investigation question*, the two scorers' scores accounted for 73% of intrascorer variance with an intraclass correlation coefficient of .79 ($p < .001$). The high Cronbach's $\alpha$ value (.83) also suggests a strong degree of internal reliability for this feature measure.

To evaluate students' written explanations, we adapted the P-SOP to develop a four-part scoring rubric (Table 3). The scoring rubric aligns with the epistemic commitments

**TABLE 3**
**Components of Students' Scientific Explanations**

| Measure | Level Description | Score |
|---|---|---|
| 1. Students formulate explanations about phenomenon of interest that are based on evidence | The formulated explanation includes causes of effect or establishs relationships based on empirical evidence. | 3 |
| | The formulated explanation includes causes of effect or establishes relationships that are partially supported by evidence. | 2 |
| | The formulate explanations for causes of effects or establish relationships that are weakly supported by evidence. | 1 |
| | The formulated explanation is not supported by evidence. | 0 |
| 2. Students formulate explanations about phenomenon of interest that answer investigation question | The formulated explanation fully answers an investigation question. | 3 |
| | The forumlated explanation partially answers an investigation question. | 2 |
| | The forumulated explanation weakly answers an investigation question. | 1 |
| | The formulated explanation does not answer an investigation question. | 0 |
| 3. Students formulate explanations about phenomenon of interest that propose new understanding | The formulated explanation illustrates learning: New explanation is different from preexisting explanation and proposes new understanding. | 3 |
| | The formulated explanation proposes new understanding about some aspect of the preexisting explanations. | 2 |
| | The formulated explanation is similar to and reinforces the preexisting explanation. | 1 |
| | The formulated explanation does not propose new understanding. | 0 |
| 4. Students formulate explanations about phenomenon of interest that build on their existing knowledge | The formulated explanation builds on existing knowledge. There are clear connections between preexisting explanations and new generated explanations. | 3 |
| | The formulated explanation is partially based upon preexisting explanations. Some element of the new explanation is based on some element of their preexisting explanation. Other aspects of their preexisting explanations may yet be unresolved. | 2 |
| | Some relationship is evident between the preexisting and new explanations, though the former may not ground the latter. Their new and old explanations may exist simultaneously rather than the latter building upon the former. | 1 |
| | No relationship is present between preexisting and new explanations | 0 |

of explanation-construction (Hapgood et al., 2004; Hardy et al., 2006; NRC, 2000, 2012; Zangori et al., 2013) and with the four components of explanation-construction identified in the P-SOP (Forbes et al., 2013). To address all four indicators for explanation-construction, we read each student artifact to assess in what ways students were engaging with the four measures. We did not examine the written explanations for explicit statements of each measure, but rather we examined each student artifact in its entirety to assess if the elements were present and if the written explanation addressed the measures in some way.

For example, to assign a score to the measure *formulate explanations about phenomenon of interest that answer investigation question*, we examined each artifact for an investigation question and then examined the written explanation in light of the investigation question. For each sample, we asked whether the student's explanation answered the investigation question and, if so, in what ways it answered the question. For a student to fully answer the investigation question, all elements of the question had to be addressed in the explanation (Table 3). For an investigation question recorded in an artifact from Grace's classroom, "How do the properties of seeds compare in different kinds of fruits?" (S7, GL2; see Table 4), we examined the written explanation for a discussion of different seeds in different fruits and how they are alike and different. In her explanation, the student included evidence that the different fruits each contained different seed numbers and draws the conclusion that "the bigger the seed the less seeds. The smaller the seed the more seeds." The student addressed property through seed number and seed size and has fully answered the investigation question. This explanation scored a three for the measure *formulate explanations about phenomenon of interest that answer investigation question* (see Table 4).

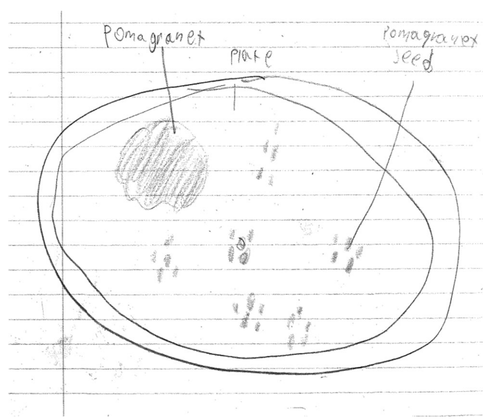
Each explanation was given a score for each measure. The measure scores were summed for each student artifact, providing a composite score ranging from 0 to 12. The first author scored all of the notebook entries. However, prior to scoring all lessons, the authors discussed the rubric and scored together a sample of student artifacts across all three classrooms and lesson to ensure the rubric was adapted from the P-SOP appropriately and the level articulations were appropriate for scoring.

Of the 177 written artifacts collected from students' science notebooks, 29 samples contained no writing pertaining to the lesson. These samples were removed from the data set, leaving 148 student samples available for analysis. The scores for the student writing samples were imported into Statistical Analysis System (SAS; 2013) for multiple regression analysis to examine the relationship between the student writing samples, each teacher's enactment, and each lesson. Our general regression model was log $y$ (writing samples) = $\beta_o$ (error) + $\beta_1$ (teacher$_i$) + $\beta_2$ (lesson$_i$) + $\beta_3$ (teacher$_{i\,\times}$ lesson$_i$). We established prior to analyzing the data that the student written artifact, data were not normally distributed due to an abundance of zero composite scores; therefore, the data required a log transformation of the regression outcome (Kleinbaum, Kupper, Muller, & Nizam, 1998). The general regression model includes the relationship between the writing samples, the teacher, and the lesson for each individual teacher. This model was also expanded to a complex model that included all three teachers, all three lessons, and all three interactions where we used "dummy" variables to categorize the teacher and lesson of interest as a 1 and 0 otherwise. We also examined the relationship between the interaction of enactment and lesson with the student writing samples. If an interaction is present, it indicates that neither the enactment nor the lesson individually affected what the student wrote, but rather it is some combination of enactment and lesson that are affecting the student artifacts (Kleinbaum et al., 1998).

## Qualitative Analysis

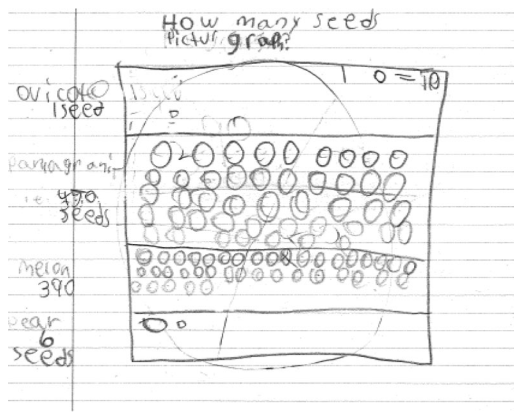
The qualitative portion of this study is a holistic, naturalistic inquiry (Denzin & Lincoln, 2000) using students' writing samples, video-recorded observations, and the teacher interviews. All data were imported into Atlas.ti and coded using classical content analysis (Ryan & Bernard, 2000) for a priori codes of the measures identified in Table 3. Source triangulation was achieved across multiple data sources (e.g., in-depth semistructured interviews, reflective grounded interviews, and lesson observations) through coding

**TABLE 4**
**Student Scoring Sample**

| | Grace (S7, GL2) | Explanation Rubric Score |
|---|---|---|
| Question | How do the properties of the seeds compare in different kinds of fruits. | The formulated explanation fully answers the investigation question as the student addressed property through seed number and seed size in his conclusion. **Score: 3** |
| Prediction | The[y] compare different kinds of fruits because the bigger the fruit the bigger the seed. The smaller the fruit the smaller the seed | The formulated explanation illustrates learning. The new explanation of "The bigger the seed the less seeds. The smaller the seed the more seeds." demonstrates that he has changed his thinking from a correlation between fruit and seed size to a correlation between seed size and seed number. **Score: 3** |
| Observation |   | The formulated explanation is partially based upon preexisting explanations. We see that some element of the new explanation (seed size) is based on some element of his preexisting explanation (seed size). However we do not know in this example if the student resolved his issue with fruit size and its relationship to seed size. **Score: 2** |

(*Continued*)

**TABLE 4**
**Continued**

| | Grace (S7, GL2) | Explanation Rubric Score |
|---|---|---|
| Data Analysis |  | The student refers to the seed count numbers in the explanation. Therefore the explanation established a relationship based on empirical evidence of seed count numbers. **Score: 3** |
| Explanation | . . . The ovicodo [avocado] seed was brown. The pear seeds were black. The pomegranate seeds were a dark pink color. There wer[e] 450 seeds in the pomegranate. The melon had 390. The pear had 6 and the ovicote [avocado] had 1. The bigger the seed the less seeds. The smaller the seeds the more seeds. | **Total written explanation score: 11** |

by two researchers of 10% of the data sources to look for consistency across sources. Interrater reliability among the texts averaged at 90% and, after discussion among the raters, a 100% agreement was reached.

For Research Question 1, each student notebook was examined holistically to identify themes and patters in the student artifacts within and across teachers. For Research Question 2, we engaged in cross-case analysis of coded data focused on the construction of a multiple-case study of the three teachers. Interview data and observations were examined together to establish themes within and across teachers. The data were triangulated through analysts and sources (Patton, 2001). All qualitative analysis involved an iterative process of data coding, displaying, and verification (Ryan & Bernard, 2000) to provide insight into the students' written explanations, the teachers' instructional practices during lesson enactments, and their conceptions about scientific explanations in elementary science learning environments.

## RESULTS

Overall, results from quantitative analysis of the student artifacts indicate that students in Grace's classroom formulated significantly more written explanations than students in Janet or Emily's classrooms. Findings from the qualitative analysis of observations and interviews suggest a link between the teachers' ideas about scientific explanations, teachers' instructional scaffolding, particularly through discourse, and students' written explanations.

### Students' Written Scientific Explanations

In our first research question, we asked, "How do third-grade students formulate written scientific explanations about seed structure and function?" Across the three classrooms, we found that a significant majority of student writing samples (66%) did not score for any facet of scientific explanations. Results from qualitative analysis of these student writing samples found that they were largely defined by data description without discussion of cause, effect, and mechanism. Writing samples that did illustrate some evidence of scientific explanations (34%) tended to include a cause, effect, and mechanism, though these samples had wide variations in the types of mechanisms attributed to the cause and effect.

***Quantitative Analysis of Writing Samples.*** Across the three teachers and three lessons, there was a statistically significant difference among the presence of explanation-construction in the writing samples. We found a significant interaction between the teachers and lessons affecting the student written artifacts, $F$ [4, 62] = 10.23; $p$ = .0367. To discover the effect of the lessons and the teachers on students' written explanations, we used a one-way analysis of variance (ANOVA). We found a statistically significant difference across the teachers' enactments for Lesson 1, $F$ [2, 56] = 11.28, $p$ = .0035, and Lesson 3, $F$ [2, 56] = 9.17, $p$ = .0102. As shown in Figure 1, these differences are due in each instance to the high level of explanation-construction observed in students' written artifacts from Grace's classroom.

Next, to examine whether the interaction also occurred within each individual teacher's three lessons, we again used a one-way ANOVA to examine a single teacher across her three enactments. We found that each teacher was consistent across her three enactments for the presence of students written explanations ($p$ values per teacher were >.06). Taken together, both sets of results indicate that, while lesson-specific opportunities for explanation-construction were similar across the three lessons for each teacher, opportunities afforded to students within each lesson varied significantly between the three teachers.

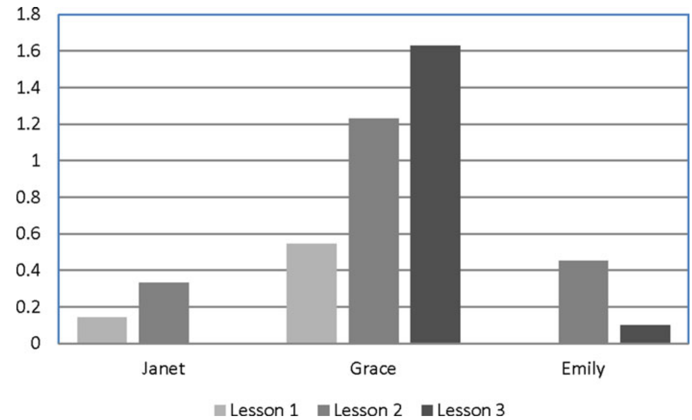


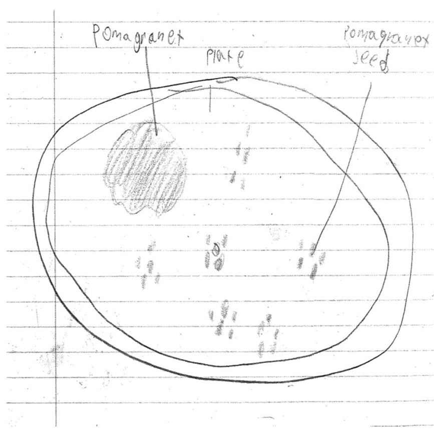
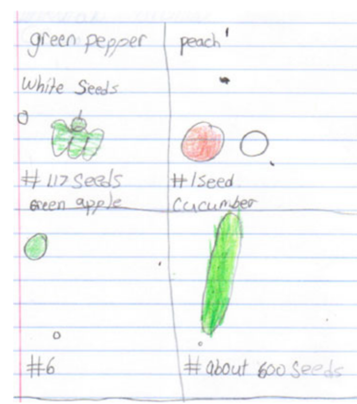
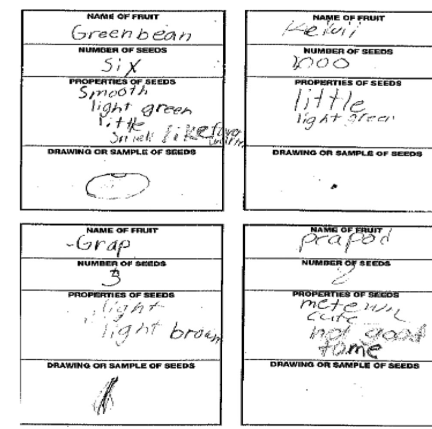

**Figure 1.** Mean scores for *formulating evidence-based explanations* in the student's writing samples across lessons and classrooms.

***Qualitative Analysis of Writing Samples.*** As suggested in the results of quantitative analysis of student artifacts, our qualitative analysis find that that student writing artifacts from Grace's classroom most frequently exhibited one or more indicator of scientific explanations. The written explanations most frequently were *based on evidence* and *answer the investigation question.* Overall, we found few samples that coded for *propose new understanding* or *build on their existing knowledge*, but those few that contained these elements were also from Grace's classroom. We found few examples from either Janet's or Emily's classrooms that coded for any measure of explanation-construction.

Samples from Janet's classroom rarely coded for explanations because writing artifacts typically only contained recorded data collection from the lessons without an investigation question. All samples included a paragraph after data collection entries titled "After the Lesson." In these entries, students wrote freely but their writings rarely met the explanation measures. A typical "After the Lesson" response from Janet's classroom was a student reflection on the portion of the lesson they most enjoyed, which frequently did not include the investigation itself. For example, in Lesson 2 students were provided a range of fruits to observe and record properties, dissect, count (or estimate), and distinguish patterns among the different kinds of seeds. After the lesson, Janet provided opportunities for the students to taste all of the fruit. A common "After the Lesson" student entry for this lesson was a discussion of how the fruit tasted (Table 5). While eating the fruit was important as many students had never tasted the fruits examined during the lesson, it was not the key concept of this lesson, which was that different fruits have seeds of different size, shape and quantity.

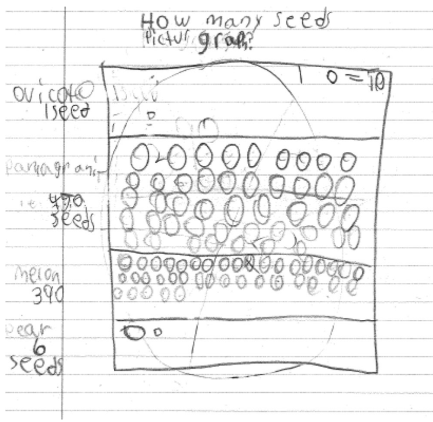
Writing samples from Emily's classroom did include investigation questions, predictions (or hypothesis), data collection, and a conclusion (Table 5). Yet the written explanations from Emily's lessons rarely included mechanisms for *how* and *why* phenomena occurred. For example in Lesson 2 (Table 5), the artifacts from Emily's classroom recorded two investigation questions: "Where do seeds come from?" and "How are seed properties alike and different?" For example, the typical prediction statement this lesson was "I think some of the colors, texture, smell, size, and shape [of the seeds] will be different and alike" (S7, EL2) and a typical conclusion was "Properties of seeds are alike and different because some seeds can have the same size, color and shape." (S7, EL2). While these responses do *answer the investigation question*, they include no mechanism for *how* and *why* seeds come from fruit or seed properties are alike and different because the investigation questions they were posed did not require sense making to answer it.

**TABLE 5**
**Student Artifact Samples for Lesson 2**

| | Grace (S7, GL2) | Emily (S2, EL2) | Janet (S10, JL2) |
|---|---|---|---|
| Question | How do the properties of the seeds compare in different kinds of fruits. | Where do seeds come from? How are seeds properties alike and different? | None |
| Prediction | The[y] compare different kinds of fruits because the bigger the fruit the bigger the seed. The smaller the fruit the smaller the seed | I think seeds come from fruits. | PREDICT:What will be inside. I think it would be a pea, flat spot's, smooth, hard, bummpy [bumpy], it could look bummpy [bumpy] but it could [be] smooth. |
| Observations |   |   |   |

(*Continued*)

**TABLE 5**
**Continued**

| | Grace (S7, GL2) | Emily (S2, EL2) | Janet (S10, JL2) |
|---|---|---|---|
| Data Analysis |  | None | None |
| Conclusion | . . . The ovicodo [avocado] seed was brown. The pear seeds were black. The pomegranate seeds were a dark pink color. There wer[e] 450 seeds in the pomegranate. The melon had 390. The pear had 6 and the ovicote [avocado] had 1. The bigger the seed the less seeds. The smaller the seeds the more seeds. | I was correct because seeds do come from fruit. I think seeds come from fruit. | After the lesson we got to eat apples, kiwi, pea pods, cherry tomato, green bell peppers and grapes, last but not lest [least] avocodo [avocado]. I was so suprized [surprised] because know [no] one like's the bell pepper. Well I can tell you the bell pepper was so nasty and hot and spicy. |

The writing artifacts from Grace's classroom included investigation questions, predictions (or hypothesis), data collection and analysis, and a conclusion. The students' written conclusion sections most frequently included connections between cause, effect, and mechanism. For example, for Lesson 2, Grace's students recorded the investigation question, "How do the properties of the seeds compare in different kinds of fruits?" (S7, GL2). Their typical predictions discussed a specific property of the seed such as "The[y] [seed properties] compare ... because the bigger the fruit the bigger the seed. The smaller the fruit the smaller the seed" (S7, GL2). Students then collected many observations of different kinds of fruits and drew picture graphs of the number of seeds found in each kind of fruit dissected (Table 5).

In their conclusion statements, the students typically exhibited sense making between the different fruits and different properties of seeds contained within each fruit. Our results indicate that two dominant themes occurred within the student artifacts from Grace's lessons. The first we considered as sophisticated explanations because the students made connections that were scientifically acceptable but outside of the range of content available to them during this lesson. For example, in Lesson 2 we found some students concluded that a correlation existed between the properties "seed size" and "seed number" (Table 5). The student appropriately connected the relationship between seed mass and seed number even though this relationship was not included in the lesson materials or enactment.

The second type of conclusion we found across all artifacts from all three of Grace's lessons we considered as naïve explanations because while students made connections between their evidence and explanation, their explanations were grounded in naïve mechanisms. For example, in Lesson 2, students' conclusions contained the notion that seed development in the plant was a constantly occurring process despite maturation and/or the fruit being removed from the plant. A typical response for this type of naïve explanation was "Some of the seeds were small. Some fruits had alot [sic] of seeds. Some fruits just had a c[o]uple ... If there was only a c[o]uple small seeds it [the fruit] was not ful[l]y grown" (S3, GL2). While this conclusion statement is *based on evidence* and *answers the investigation question*, and the student shows evidence of sense making by providing an explanation for *why* some fruits had less seeds, the explanations is situated in a naïve mechanism that fruit maturation never stops occurring.

## Elementary Teachers' Instructional Support of Explanation-Construction

In our second research question, we asked, "In what ways and why do third-grade teachers provide instructional support for students' formulation of scientific explanations about seed structure and function?" We analyzed the teachers' interviews and lesson enactments to explore how and why the teachers did (or did not) enact unit lessons to support their students to engage in scientific explanation-construction. Across the nine lessons, we identified 19 episodes of teacher–student discourse, mostly in Grace's classroom, where teachers enacted modified versions of unit lessons to support students to connect cause and effect with a mechanism. There were clear trends in the teachers' reasoning about explanation-construction that aligned with their instruction. Across the three teachers, our results illustrate two dominant models evident in the teachers reasoning and instructional practices around explanation-construction: correct explanations and self-as-explainer.

***Emily and Janet: Correct Explanations.*** Emily and Janet viewed the curriculum as the locus of control. They both articulated that it was important for students to engage in "recipe-driven" (04:01:52) investigations because they need to be provided the scientific facts. As Emily stated, sometimes a lesson has "got to be 'here, let me tell you [what the answer should be]. Now you model it or draw it and then we will move forward'" (04:1:53) because, as she articulated, there was factual information students needed to know to engage in the investigations. Both teachers stressed the importance of students coming to the "correct" explanation that they interpreted as factual information. They also both emphasized they were concerned with time requirements to enact science lessons. They expressed concern that if they engaged their students with *why* questions and deviated from their curriculum materials, it would take a great deal of time for students to arrive at the scientific facts the lesson stressed.

We also found that both teachers struggled with what a scientific explanation might look like in the elementary classroom and whether it was something that should involve students determining whether their prediction was "right" or "wrong." Janet and Emily emphasized correct explanations in both their verbal discussions with students and their support for students' written explanations. Both focused their writing instructions on directing students to write what the investigation "should show" which they established from the curriculum materials (i.e., Lesson 1: seeds come from fruit, Lesson 2: different seeds have different properties, and Lesson 3: seeds sprout in the presence of water without soil).

As illustrated in the analysis of the student writing samples, Janet used her science notebooks the least of the three teachers. She was the only teacher that used the curriculum-provided data collection worksheets for all three lessons, and she read aloud from her curriculum materials prior to asking her students to write their "After the Lesson" statements. For example, in Lesson 2, after students had completed dissecting their fruits, she read directly from the curriculum materials and stated, "A plant part that contains seeds is called a fruit." She then gave her students the writing prompt, "After the lesson I learned . . . ," and provided no further instructions for what students should consider or address in their writings. As observed in the student writing samples, this frequently resulted in students stating whether they were "correct" or "incorrect" in their conclusions and frequently did not score for explanation-construction (Figure 1; Table 5).

Unlike Janet, there were instances where Emily was able to provide instructional scaffolding to her students by affording them opportunities to formulate explanations. For example, in Lesson 3, students were examining the sprouting differences between four different types of seeds (bush bean, pea, and sunflower and popcorn seeds) in hydroponic growth. Their investigation question for this lesson was "What happens to seeds in water?" Emily supported a student in cause, effect, and the underlying unseen mechanism for why he was observing sprouts coming from the seed:

T: What other changes have you noticed [to your lima bean]?
S: It's cracking open and grown a stem . . .
T: What does this tell you about the seed?
S: It's changing a lot.
T: Why is it changing a lot?
S: Because of the water. The seeds are in water.
T: OK. Why did the water change the seeds?
S: Because the seeds need water to grow.
T: Why?
S: Um . . . because water . . . because seeds are living things. (Emily, 1a/7:53)

She prompted her student to connect the cause with the effect ("What other changes have you noticed?" and "Why is it changing a lot?), then asked her student "Why?" two additional times leading this student to attribute a mechanism ("seeds are living things") to the cause and effect which answered their investigation question of "what happens to seeds in water."

However, this example of scaffolding a student to articulate a mechanism was a rare occurrence in Emily's classrooms and, as observed in the student artifacts, did not translate to students' writings (Figure 1). Like Janet, Emily struggled with what her students should write in the conclusion section of their science notebooks and how best to enact her curriculum when she asked students to write a conclusion. It was common in Emily's enacted lessons for her to ask students to use the conclusion section to "tell me whether or not your hypothesis was correct or incorrect" (Emily, 3c/3:43). However, while she identified the conclusion as the place for her students to determine whether their hypothesis was right or wrong, she also stated that the conclusion section was "something we need to work on" (04:5:26). She wondered if students should be writing more than whether their hypothesis was "right" or "wrong." When we asked her how she might work on the conclusion section with her students, she stated that she was not sure what the purpose of the conclusion section should be. As she stated, "I think I need to, myself, figure out exactly what I want" (04:7:24).

***Grace: Self as Explainer.*** Grace defined good science teaching as not providing a single correct explanation. She expressed that science instruction should not focus on "just right or wrong" (01:1:92) answers and that her intention was for her students to experience a range of varying explanations. Furthermore, she stated that it was important for students to become "comfortable with the idea that it is very possible for there to be more than one explanation for why the seed numbers differ between the different kinds of fruit" (01:4:43) because, as she identified, there is not always a single correct answer in science. Grace discussed that if her students came to their own conclusions, then they had ownership of their reasoning and she had evidence of their learning.

She noted that she was working to integrate science with nonfiction writing so it was important to her that her students be provided sufficient time for writing in their science notebooks. Grace stated that during science notebook writing, students should consider how and why phenomena occurred because these are important components of nonfiction writing. However, Grace also identified that it was "tough" (01:1:24) to teach this way because it takes time and practice to get the students used to answering why questions and it also requires "thinking deep" (01:1:20) on the part of the teacher about the lesson content and the practices of science. Grace discussed that she takes her science lessons "deeper" through her goal for her students to "be responsible for their own learning" (01:1:10), which she identifies occurs through students writing their own conclusions. She stated that it was important that students write their own conclusions because it was "evidence for me of their learning" (01:2:66). Overall, we found that Grace viewed explanation-construction as a critical means to assess students' learning.

During her interviews, she expressed frustration with her science curriculum materials because she felt they did not meet her learning goals and did not support her students in understanding the "big picture" of the lesson. She discussed that if she was to do all of the parts of the curriculum, then the lessons would be time consuming and focused on vocabulary without sufficient opportunities for students to examine their data and evidence and write their conclusions. As a result, Grace modified each of her science lessons. For example, in Lesson 1, she chose to modify her lesson because she was concerned that the focus on the vocabulary term "properties" within the materials would detract from students' learning:

> This lesson started out . . . with this apple and they were supposed to name the properties, so I was going to originally give them an apple. But, I decided not to. The only point of the

> apple was to talk about properties. So, I scratched that part ... we have to ... get to the big picture. (01:02:24–30)

For this lesson, Grace said the "big picture" is the "amount of seeds in there [the pea pod] and that seeds are in fruit" (01:02:40). She expressed concern that any discussions that did not focus on these two concepts would distract student learning from the main idea. Instead, she decided to let her students begin the investigation of seed properties without an opening discussion.

Grace consistently supported her students to formulate explanations throughout her lessons but the mechanisms she accepted from students frequently did not match the targeted concept. Instead, we observed three different outcomes occurring in her teacher–student verbal explanation episodes. First, discussions in Grace's classroom often resulted in students proposing elements of scientific explanations that demonstrated sophisticated reasoning about the phenomena, even though their proposed scientific explanations were based on concepts not covered in the lesson. For example, during Lesson 3, Grace's students were observing the differences among their bush bean, pea, and sunflower and popcorn seeds placed in hydroponic growth in the week prior. Grace visited each individual student group to discuss the observations they were making about their seeds:

T: What do you notice about your seeds? Are they sprouting the same way through?
S: The beans are sprouting um they're like twisted up together.
T: Why do you think the beans are twisted up and the popcorn–
S: Maybe it was like flipped over and it was like couldn't grow down so maybe it got all twisted up when it was trying to grow down. (Grace, 3b/19:38)

In this student exchange, the student was concluding that the roots were attempting to grow toward the gravitational pull (i.e., gravitropism)—to "grow down"—even though the direction of root growth as well as the concept of gravity was not included in the lesson content. We considered this an example of sophisticated reasoning as the student was correct in their mechanism even though it was outside of the targeted lesson concept.

Second, we observed her verbally supporting student explanation-construction that included student evaluation of their prior understanding in light of new evidence. For example, in Lesson 3, she engaged an individual student in a discussion about seed growth who had verbally expressed at the beginning of the lesson that he thought a popcorn seed would only grow when planted in "hot stuff" (Grace, 3a/24:25) to grow a root. The student hypothesized that the popcorn seed would be unable to grow unless it was placed in the microwave to receive "hot stuff." When Grace stopped at his table to question his current thinking about his hypothesis, the student identified that the he no longer thought the popcorn seed needed to be in "hot stuff." Grace continued the discussion prompting the student to provide her his evidence for his current thinking about how a popcorn seed grows. She also prompted this student for a mechanism for *how* and *why* the seed did not have to be in hot stuff in which he made connections that seeds are living things, and all seeds sprout in the presence of water and air.

Third, we observed 12 episodes across Grace's three enacted lessons where students proposed naïve mechanisms grounded in the evidence from their investigation. This theme aligns with Grace's students' written explanations, which also included many naïve mechanisms. In each instance where these types of mechanisms occurred, we did not observe Grace attempt to question her students in identifying the scientifically accepted mechanism for the cause and effect they observed. For example, in Lesson 2, she asked students during a small group discussion why they thought seeds were located in different places inside different kinds of fruit. The students offered that "when they picked up the fruit, the juice inside moved them [the seeds] around" (Grace, 2a/8:16). Grace offered that this was a "great explanation!" (Grace, 2a/8:16) and did not return to this explanation again over the course of the lesson enactments.

### Summary

Overall, study findings suggest a link between the teachers' ideas about scientific explanation construction during enactments, the presence of verbal explanation construction during their lessons, and student writing outcomes. Grace had the strongest conceptions of how scientific explanations may be enacted in the classroom, which she incorporated spontaneously in her lesson enactments. Moreover, her classroom had a statistically significant outcome for the increased presence of written explanations as compared to the other two classrooms. However, while Grace's students' explanations were more frequently grounded in evidence (i.e., scientific) and answered the investigation question, they also illustrated a range of naïve mechanisms related to seed structure and function.

## SYNTHESIS AND DISCUSSION

Scientific explanation is a crucial scientific practice to foster elementary students' conceptions about the world (Duschl et al., 2007; Metz, 2008; NRC, 2012). Prior studies examining elementary students' engagement with scientific explanation-construction have shown some evidence of success. Yet it is important to note that these studies have predominantly relied upon researcher- and teacher-designed curriculum materials (e.g., "boutique" curriculum) to address these important facets of learning and instruction (e.g., Hapgood et al., 2004; Hardy et al., 2006; Herrenkohl et al., 1999; Mason, 2001; Metz, 2008). Off-the-shelf science curriculum materials may not foreground scientific reasoning (Metz, 2004), and researchers are only just beginning to examine the ways in which in-service teachers use these materials in elementary classrooms (Beyer & Davis, 2008; Biggers et al., 2013; Forbes & Davis, 2010; Forbes et al., 2013; Zangori et al., 2013). Further research is needed on the teacher–curriculum relationship so science educators might better understand ways to support both preservice and in-service teachers to plan with and enact these materials. The results presented here begin to shed light on how teachers use elementary science curriculum materials to foster students' explanation-construction about plant growth and development. In particular, they suggest a link between teachers' ideas about scientific explanations as a component of classroom inquiry, the instructional support they provide students for explanation-construction, and students' written explanations for seed structure and function.

First, students' written explanations show that while a small number of students were engaging in scientific reasoning, we found few scientific explanations in students' written work. The majority of students' written samples were composed of observations or statements without evidence. These types of statements do not only constitute scientific understanding because the students have not been asked to engage in knowledge production, only to provide a written account of their observations (Duschl et al., 2007; Braaten & Windschitl, 2011; Metz, 2008; Salmon, 1998). While the students here had multiple and lengthy opportunities to engage in hands-on activities with seeds, fruit, and seed growth, their written work did not indicate that they engaged in sense making about their investigations (Biggers et al., 2013; Forbes et al., 2013; NRC, 2000, 2012; Zangori et al., 2013). This finding suggests that despite calls for providing student opportunities to develop conceptual understanding of plant growth and development through multiple and varied hands-on engagement opportunities with plants (Barman et al., 2006; Canal, 1999; Jewel, 2002; Patrick

& Tunnicliffe, 2004), such opportunities were relatively limited and must be carefully crafted to promote students' learning.

The small portion of students that were afforded opportunities to engage in scientific reasoning did so in varied ways. These instances when cause, effect, and mechanism were generated by the third graders were grounded in evidence, answered an empirical question, and in some instances, built upon and extended students' understanding. Each of these are critical epistemic commitments of explanation-construction articulated by the NRC (2000, 2012) and emphasized in past research (Biggers et al., 2013; Forbes et al., 2013; Mason, 2001; Ryu & Sandoval, 2012; Zangori et al., 2013). Since early learners' reasoning is constrained by the domain-specific conceptual knowledge they have available, in its absence, students will rely upon intuitive patterns in their evidence to generate explanations (Duschl et al., 2007; Schauble, 1996; Zuzovsky & Tamir, 1999). However, plant structure and function is a complex biological system made up of many underlying, unobservable mechanisms and connections between abiotic and biotic factors (Patrick & Tunnicliffe, 2011; Schussler, 2008; Wandersee & Schussler, 1999). While this was occasionally fruitful, such as when students recognized the correlation between seed size and seed number, these instances were rare. More frequently, if students engaged in scientific reasoning, they attributed alternate conceptions to their evidence about seeds, fruit, and seed growth, as has been found in prior research about students' alternate conceptions about plant growth and development (Barman et al., 2006; Canal, 1999; Jewel, 2002).

Second, this study sheds light on the teachers' conceptions and orientations toward explanation-construction as a scientific practice. On the one hand, when teachers identify with the "correct explanation" model (Horwood, 1988; Zuzovsky & Tamir, 1999), they may not provide support or opportunities for their students to engage in sense making. This may be because the teachers assume that they have provided their students with the "right" information from the curriculum so no further engagement in scientific explanations or evaluation of scientific explanations is necessary. However, in this manner, the science content becomes separated from knowledge-building processes (Braaten & Windschilt, 2011; Metz, 2008).

On the other hand, when teachers identify as "self-as-explainer" (Horwood, 1988; Zuzovsky & Tamir, 1999), the reasoning activity itself, without concern of content, becomes the goal of the lesson. The focus within this model is on student generation of *any* mechanism for cause and effect regardless of its scientific acceptability. While this model may engage students in scientific reasoning, it does not include consideration of the manner in which students interpreted their data and evidence for cause and effect or the scientific acceptability of *how* and *why* the phenomenon occurred. Teachers who align with this model view the epistemic practice of science as separate from domain-specific knowledge (Metz, 2008; Ryu & Sandoval, 2012).

Yet, despite these different ideas about scientific explanations, our results indicate commonality among the three teachers' views as to *where* scientific explanations fit within instruction. While the teachers had different ideas about the ways scientific explanations should be incorporated into their enacted lessons, all three teachers were uniform in their view that the scientific explanation is the outcome and conclusion to the investigation. In other words, the teachers viewed scientific explanation is the means to an end for the science lesson (Beyer & Davis, 2008). This is problematic as it does not provide students opportunities to compare and evaluate their explanations, an uncommon practice in elementary science classrooms (Biggers et al., 2013). Without this crucial next step, student opportunities to engage in knowledge production and develop scientific understanding are severely limited (Duschl et al., 2007; Jewel, 2002; Mason, 2001; NRC, 2000, 2012; Schauble, 1996).

Finally, third, study findings suggest that both the instructional support and scaffolding teachers provided students to formulate explanations reflect their ideas and conceptions of scientific explanations in elementary science learning environments. All three teachers had to depend on their own ideas about scientific explanations and student learning because their materials did not support them in scaffolding this practice within their lessons. Prior research suggests that elementary students can effectively engage in scientific reasoning when provided synergistic support (Tabak, 2004) from the teacher, their curriculum materials, and through classroom discourse (Hardy et al., 2006; Herrenkohl et al., 1999; Mason, 2001; Metz, 2008, 2009; Ryu & Sandoval, 2012; Zuzovsky & Tamir, 1999). However, a core component of inquiry investigations is providing students opportunities to generate explanations and compare and evaluate their explanations against prior knowledge, other students' explanations, and/or other scientific explanations (NRC, 2000, 2012). In this manner, students have opportunities to engage in the practices of science and examine their preexisting mechanism libraries for adequacy in explaining the phenomenon (Duschl et al., 2007; Mason, 2001; Schauble, 1996).

This approach to explanation construction is the "structure of science" explanation model (Horwood, 1988; Zuzovsky & Tamir, 1999), which we did not observe with the teachers studied here. This model of explanation-construction provides a middle point along the more teacher- or student-directed continuum of explanation construction. This may be a more advantageous model for both teachers and students to engage in explanation-construction because it provides opportunities for students to generate explanations, but then supports students to evaluate those explanations until a single satisfactory explanation is constructed. As the NRC 2012 study suggests, "... knowing why the wrong answer is wrong can help secure a deeper and stronger understanding of why the right answer is right" (p. 44) and the "structure-of-science" model would support teachers in helping their students develop scientific understanding in each instance. However, this requires that teachers use their curriculum materials in a flexible manner modifying the materials where they, and their students, require support in connecting cause, effect, and the scientifically acceptable mechanism as a learning goal of the lesson.

## IMPLICATIONS

Addressing all components of scientific explanations is required for conceptual change (NRC, 2012), but not all facets of explanation-construction are intuitive (Braaten & Windschitl, 2011; Duschl et al., 2007). While elementary science curriculum materials should afford students meaningful sensemaking opportunities through engagement with plant phenomena in ways that link students' prior knowledge to targeted concepts and challenge student's alternate conceptions, these opportunities are atypical (Biggers et al., 2013; Forbes et al., 2013; Metz, 2004, 2008; Ryu & Sandoval, 2012; Zangori et al., 2013). To create a coherent learning experience that aligns with the practices of science, elementary science learning environments must be composed of scaffolds that work synergistically (Tabak, 2004) with the curriculum, associated tools such as science notebooks, and instruction. For this to occur, an emphasis on process and content must be carefully intertwined (Herrenkohl et al., 1999; Metz, 2008; Schauble, 1996). Therefore, these findings have important implications for both professional development and curriculum development.

Curriculum materials should be designed to afford students opportunities to formulate scientific explanations that connect cause, effect, and mechanism (NRC, 2012). Although no formal review of elementary science curriculum materials has been conducted (Kesidou & Roseman, 2002), results of some studies suggest that elementary science curriculum materials underemphasize explanation-construction (Biggers et al., 2013; Forbes et al., 2013; Zangori et al., 2013). In these instances, the materials focus heavily on engagement with phenomena and data collection but typically do not ask students to consider causal inferences. For elementary students to be successful in developing scientific understanding of plant structure and function, students should have opportunities to focus on the key processes with the underlying unobservable mechanisms made explicit. For example, the curriculum studied here provided surface explanations such as "seeds are contained in fruit," without providing students access to the underlying causal mechanism for *how* and *why* seeds are contained in fruit. Without providing students access to this fundamental function of seeds within the plant life cycle, then the process appears "magical" because students do not have a reason for why they are finding seeds in fruit (Schussler, 2008). Furthermore, students require opportunities to compare and evaluate their explanations with other scientific explanations to arrive at consensus of the acceptable scientific mechanism (Ryu & Sandoval, 2012). Without providing students access to these critical facets of explanation-construction, then their preexisting mechanism libraries about seed structure and function will not be challenged and naïve conceptions about plant growth and development will remain.

Effective curriculum materials should also include components that are educative for teachers themselves (Davis & Krajcik, 2005). If curriculum is educative for the ways in which to support students in practices of science and the conceptions included within the materials, teachers will be better equipped to understand where student conceptual knowledge may need to be bolstered and make lesson modifications as needed. Curriculum materials should also provide teachers with ideas about the typical alternate conceptions students bring with them about plant growth and development, so they are prepared to engage students in examining these naïve mechanisms and develop new understanding (Barman et al., 2006; Canal, 1999; Jewel, 2002; Patrick & Tunnicliffe, 2004). Educative curriculum materials would provide examples of early learners' engagement with scientific reasoning and what these episodes can look like in the elementary classroom. Furthermore, the nature of educative materials is to support teachers' pedagogical reasoning about the tasks included in the lesson rather than for teachers to use the materials as a script (Davis & Krajcik, 2005). In this manner, teachers can be flexible with their materials (Remillard, 2005) and determine where opportunities for sense making would be most appropriate and the ways in which to engage their students in these opportunities.

## CONCLUSIONS

This study contributes to a limited body of research on elementary students' learning about plants and explanation-construction in elementary science learning environment, which provides possible explanations as to why students' naïve mechanisms about plant structure and function persist after almost three decades of research (e.g., Barman et al., 2006; Canal, 1999; Jewel, 2002; Patrick & Tunnicliffe, 2011; Wandersee & Schussler, 1999). Elementary students' opportunities for active sense making (Mason, 2001; Ryu & Sandoval, 2012) are often rare, and, when included, may not result in students replacing naïve mechanisms with scientifically acceptable ones (Hardy et al., 2006). Despite calls for providing students with opportunities to develop conceptual understanding of plant growth and development through investigation (Barman et al., 2006; Canal, 1999), findings from this study suggest that such experiences in the elementary grades may not always foster and promote conceptual change.

This work supports and extends the notion that elementary teachers' pedagogical understanding of explanation-construction and science content requires strengthening, which has implications for science educators and curriculum developers. Future research should explore other widely available off-the-shelf elementary curriculum materials for inclusion of scientific-explanation construction and the coherence of science content to explore whether this issue is endemic across elementary curriculum materials. Future work should also investigate how widely used curriculum materials may be supplemented to support both teacher and student learning in formulating scientific explanations and meeting the new science education standards (NRC, 2012) that include both modeling and argumentation frameworks—neither of which was present in the curriculum studied here. Such work will help science teacher educators and curriculum developers better understand how to support teachers to promote explanation construction in their classrooms.

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