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ABSTRACT

Building on the work of teacher noticing, this study investigated teachers' noticing of students' thinking evident in artifacts from their science teaching context. Prior work on teachers' noticing in science has generally focused on noticing students' thinking surrounding specific disciplinary content. We asked 20 elementary teachers to identify and discuss an artifact that represented their students' thinking in science. Rather than discuss specific disciplinary content, teachers described what students were "doing" in producing that artifact. The results of this study demonstrate attending to what students are doing is one way teachers notice students' thinking in science, and in these descriptions of "doing" lie important connections to the scientific and engineering practices of the Next Generation Science Standards. This study can inform the design of teacher learning experiences in which artifacts and teachers' tendency to focus on what students are doing can be leveraged toward learning to notice students' thinking in science.

KEYWORDS

artifacts; elementary science teaching; NGSS; scientific and engineering practices; students' thinking; teacher noticing

Science education researchers largely agree that in order for meaningful science learning to occur, teachers must pay close attention to their students' thinking (National Research Council [NRC], 2007, 2012). Paying close attention involves not only noticing what students say and do but also making sense of and responding to those moments in order to support students in forming coherent scientific understanding of phenomena in the world (Levin, Hammer, & Coffey, 2009; Robertson, Scherr, & Hammer, 2015). This is the premise we start with—that teachers' noticing of students' thinking is essential to learning in science. Thus, students' thinking—in all of its complexity and messiness—needs to be visible as learning unfolds. In other words, science learning must involve opportunities for students to communicate their thinking so teachers can notice, make sense of, and respond to that thinking. In fact, current reforms in kindergarten–Grade 12 (K–12) science education support a vision of science learning in which these opportunities to communicate one's thinking arise as a result of engaging in the practices of science and engineering (NRC, 2012). In other words, when students are planning and carrying out investigations, asking questions, and designing a solution, among other practices, their thinking is made visible. These current reforms also support a vision of science teaching in

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which actively noticing students' thinking as they engage in these practices is an essential component of science teaching (NGSS Lead States, 2013; NRC, 2012).

In previous work examining elementary teachers' interactions with science curriculum materials in a science learning context (Selmer, Luna & Rye, 2015), we found that teaching- and learning-related factors—including a focus on students' thinking—were mostly absent. We found this both curious and troubling and wondered whether the teachers in this study did not focus on students' thinking when teaching science in this context (we doubt this assertion) or whether they did, but in a way that our previous study did not uncover (we find this assertion more likely). Therefore, these findings and the idea that teachers' attention to students' thinking is essential for meaningful science learning to occur prompted and supported our current study, in which we examined what teachers identify as artifacts of students' thinking in science. Specifically, we sought to answer three research questions:

RQ1. What do teachers identify as an artifactual representation of students' thinking in a science learning context?
RQ2. How do teachers describe these artifacts as representations of their students' thinking in science?
RQ3. In what ways are science and engineering practices evident when teachers identify and describe an artifact that shows their students' thinking in science?

This study investigated these questions in an elementary school context with a group of 20 teachers at the end of their school's third year of implementing garden-based learning (GBL) as part of the science curriculum.

Literature review and theoretical framework

The vision for K–12 science education compels teachers to notice students' thinking

The vision and goals of K–12 science education inherent in both *A Framework for K-12 Science Education* (NRC, 2012) and the subsequent Next Generation Science Standards (NGSS; NGSS Lead States, 2013) describe science teaching as structuring learning around three interconnected disciplinary dimensions—scientific and engineering practices, cross-cutting concepts, and disciplinary core ideas—in order to support students in forming coherent understanding of scientific phenomena in the world. This vision of science teaching is different from that inherent in past standards documents that consisted of long lists of specific topics to be taught at each grade level (NRC, 2012). Faced with such science standards in the past (and in many cases in the present), teachers naturally placed instructional emphasis on covering science content rather than on engaging students in the practices of science and scientific thinking. Consequently, in science classrooms teachers tended to emphasize science facts, vocabulary, and basic concepts in ways that promoted surface-level rather than deep understanding (Weiss & Pasley, 2004). The current vision for science education, in contrast, requires teachers to shift their emphasis from teaching specific facts to teaching about scientific phenomena and supporting students' thinking in pursuit of understanding such phenomena (Reiser, 2013). With the three NGSS dimensions informing science teaching and curriculum, students' ideas, then, should provide the basis for meaningful learning in science classrooms, which necessarily requires teachers to notice students' thinking.

Teachers' noticing of students' thinking

What does it mean to notice students' thinking? It involves what Sherin and colleagues (2011) described as active noticing—attending to, interpreting, and responding to certain components of the complexity present in a classroom environment. Like other researchers, we recognize that there is a lot one could notice at any given moment in a classroom, and we therefore agree that teachers need to actively notice those pedagogically important components of classroom activity that support learning (Jacobs, Lamb, & Phillip, 2010; Sherin, Jacobs, & Phillip, 2011). These pedagogically important aspects of classroom activity are also certainly varied. In science classrooms, for example, teachers could notice students displaying emotion, positioning for power, and/or discussing specific disciplinary content. Indeed, prior research specifically in science education has examined some of these different aspects of teachers' noticing. For example, researchers have attempted to describe teachers' noticing of specific science classroom occurrences such as instances of students' affect in relation to the discipline (Jaber, 2014), students' ideas becoming objects of whole-class inquiry (Maskiewicz & Winters, 2012), or students' epistemologies (Hutchison & Hammer, 2010). Other researchers have looked at teachers' attention to the science content in classroom discussions and whether students' ideas align with the canonical knowledge of the discipline (e.g., Black, Harrison, Lee, Marshall, & Wiliam, 2003; Covitt, Caplan, & Cano, 2014; Furtak, 2012; Furtak & Heredia, 2014). Yet as Coffey, Hammer, Levin, and Grant (2011) pointed out, the findings of this body of work primarily support teachers' noticing children's ideas as they are aligned or misaligned with specific disciplinary content, and as a result there is little discussion around teachers' attention to the disciplinary substance of students' thinking. In other words, the discussion in this prior work is around teachers' noticing science content rather than around students' thinking surrounding that content. This difference in what teachers attend to is particularly important because, as much of the noticing literature concludes, "what teachers attend to while they teach is highly consequential" to that which occurs in the classroom (Schoenfeld, 2011, p. 223). Furthermore, and specific to a reform vision of science teaching, what teachers attend to as students engage in the practices of science and engineering will certainly be consequential to students' constructing understanding of scientific phenomena.

Therefore, in this work, we narrow the construct of teacher noticing to that of attending to students' thinking in science. Although we acknowledge that interpreting and responding are also essential components of teacher noticing, we are curious as to the implications teachers' attending alone can have for students' learning in the current context of science education reform. We therefore present a study of teachers' attending in order to provide insight into what it is that teachers pay attention to when they are asked to notice their students' thinking in science and to engage in a discussion of how teachers' attending can become consequential to students' learning in science. Furthermore, in order to narrow the scope of this work and build on both the teacher noticing literature and the authentic science learning contexts literature, we specifically investigate what elementary teachers attend to when they are asked to notice their students' thinking in artifacts from science lessons they have taught. We discuss some of the literature that informs this work next.

Noticing students' thinking in classroom artifacts

Clearly the construct of teacher noticing, though a fairly recent construct in science education research, has become relevant to our discipline, as evidenced by the emerging body of research on the what, when, where, how, and why questions surrounding it (e.g., Levin et al., 2009; Luna, 2013; Rosebery & Puttick, 1998; Roth, 2009; Roth et al., 2011; Russ & Luna, 2013; Thompson, Windschitl, & Braaten, 2013; van Zee, Hammer, Roy, Bell, & Peter, 2005; Windschitl, Thompson, & Braaten, 2011). What is missing from this body of work, however, is research that investigates teachers' noticing involving classroom artifacts that show their students' thinking in science. To be clear, researchers in mathematics and science have studied how practicing and preservice teachers learn from classroom artifacts in professional development and teacher education contexts (e.g., Gerard, Spitulnik, & Linn, 2010; Goldsmith & Seago, 2011; Kazemi & Franke, 2004), and other researchers have examined artifacts in studies of classroom practice (e.g., Martínez, Borko, & Stecher, 2012; Ruiz-Primo, Li, Tsai, & Schneider, 2010). However, this research has not specifically looked at teachers' noticing of their students' thinking evident in classroom artifacts from science lessons they have taught. We agree that artifacts are useful tools for both supporting teachers' learning as well as studying teachers' practice. Furthermore, we contend that artifacts are useful tools for investigating teachers' noticing of students' thinking in particular because they provide a "photographic metaphor" (Lampert, 2001, p. 430) that captures a snapshot of a student's thinking occurring in the learning context in which a particular artifact was produced. Thus, artifacts provide two affordances in particular important to this work. First, artifacts are materials produced in classrooms as a result of the teaching and learning activity occurring in such classrooms (Martínez et al., 2012). And second, because artifacts are a product of classroom activity, they are ecologically valid in that they may contain cognitive, disciplinary, and pedagogical features of the classroom activity (Goldsmith & Seago, 2011). Thus, we contend that it is possible to see evidence of students' thinking related to the classroom activity in artifacts produced while they are engaged in that activity.

Noticing students' thinking in artifacts from authentic science learning contexts

In reform science classrooms specifically, classroom activity should involve students engaging in scientific and engineering practices in pursuit of coherent understanding of scientific phenomena in the world (NGSS Lead States, 2013; NRC, 2012), and therefore artifacts could result from this engagement. For example, if children are conducting an investigation to determine whether plants need soil to grow, we might expect artifacts from this investigation to include a description of how to investigate whether plants need soil to grow, a table recording measurements of plant growth in different conditions, and drawings or photographs of plant growth over time. We believe that these kinds of artifacts will certainly contain those cognitive, disciplinary, and pedagogical features of conducting this investigation and therefore contain elements of students' thinking in science—particularly if the learning context provides authentic experiences of engaging in science practices. In our work specifically, we have found that a GBL context provides those authentic experiences with the practices of science and engineering that oftentimes result in artifacts demonstrating students' thinking.

GBL: An authentic context for attending to students' thinking in science

Recent reviews of the literature on GBL provide considerable support for its value, especially at the elementary level, in providing authentic experiences and achieving positive academic outcomes, particularly in science (Blair, 2009; Williams & Dixon, 2013). However, these reviews reveal a need for considerably more research around GBL, particularly research that examines the ways in which teachers leverage a GBL curriculum to support students' meaningful science learning. In addition, as schools across the United States implement the NGSS (NGSS Lead States, 2013), there is a need for research that looks at how authentic science learning contexts, including GBL, support the kind of learning required of these new standards. The research questions at these crossroads of the NGSS, a GBL curriculum, and meaningful science learning are not only vast but also complex, involving stakeholders at all levels, including, and perhaps most centrally, the teachers implementing the NGSS in a GBL context. It is here where we situate the current study, specifically examining elementary teachers' experiences teaching science in a GBL context.

Although GBL contexts support learning across grade levels and across the curriculum (Williams & Dixon, 2013), we contend that GBL especially supports young children's learning in science, as it provides an authentic context in which to experience and learn about scientific phenomena while engaging in the scientific and engineering practices of the NGSS. A GBL context particularly supports learning around the disciplinary core ideas and crosscutting concepts associated with energy and matter. In other words, teaching science in a GBL context supports students' learning around the three dimensions of the NGSS—learning disciplinary core ideas and crosscutting concepts while engaged in scientific and engineering practices. We contend, as other researchers do, that key to successful learning in an authentic context—in this case a GBL context—is teachers' attention to the thinking that takes place in this space as children pursue understanding of phenomena in the natural world (e.g., Hammer, Goldberg, & Fargason, 2012; Lehrer, Schauble, & Lucas, 2008; Rosebery & Puttick, 1998; Stroupe, 2014; Thompson et al., 2013). Finally, it is important to note that in order for teachers to notice students' thinking, it must be made visible—that is, children must communicate their thinking in some form. We believe that actively engaging children in scientific and engineering practices in authentic science learning spaces like GBL gives an opportunity for children to communicate their thinking in different forms, and thus their thinking can be noticed.

Therefore, in this study, we examine one aspect of teachers' noticing in their science teaching practice—specifically what teachers' attend to when asked to notice their students' thinking in artifacts from their science learning context. In doing so we provide an artifact-based measure of teachers' attending to students' thinking in science. Specifically, we examine 20 elementary teachers' attention to students' thinking as they discuss student artifacts from their science classroom experiences.

Study design

Setting and participants

School context

The 20 teachers who participated in this study were faculty at Eli Elementary School,[1] a prekindergarten–Grade 5 school in a small city in the Mid-Atlantic region. At the time of this study, Eli Elementary School had just completed its third year of implementing GBL in its science curriculum. GBL at Eli Elementary School began in Spring 2011 with assistance from faculty from a nearby university, parents, community organizations, and corporate funding. The physical infrastructure of this program now includes 30 outdoor

[1]Eli Elementary School is a pseudonym. All teacher and student names throughout this article are also pseudonyms.

raised beds, classroom vermicomposting and seed germination units, and indoor gardening systems (e.g., EarthBox®).

Teacher participants

Of the approximately 30 teachers who implemented GBL activities in these first 3 years of the program, 20 agreed to participate in this study. Participants varied in their number of years of teaching experience (ranging from 3 years to more than 20 years) and included 16 regular classroom teachers (spanning kindergarten through Grade 5) as well as art, music, Chinese, and special education teachers. The research team for this study consisted of three university faculty members who had assisted with the original implementation of GBL at Eli—two were from science education and one was from mathematics education.

Data collection methodology and sources

Semistructured interviews

We conducted semistructured, task-based interviews with the 20 teachers in which artifacts from each teacher's GBL practice were discussed. Prior to the interviews, we met with all teacher participants to describe the task of selecting an artifact representing their students' thinking and to discuss different kinds of artifacts that could be selected. We did this in order to broaden teachers' idea of what a student thinking artifact could consist of (e.g., a video, a drawing). Teachers were then asked to identify and bring an artifact showing their students' thinking in GBL to the semistructured interview. During the interview, a researcher used the artifact to stimulate discussion around what the teacher noticed about students' thinking, starting with an open-ended request to tell the researcher about the chosen artifact. The researcher then followed with questions about why the teacher had chosen that particular artifact to represent students' thinking, what specifically the artifact showed about the students' thinking in science, and what the student could have been thinking when producing the artifact. This line of open-ended questioning was purposeful in that it engaged teachers in both the attending and interpreting aspects of teacher noticing.

Data sources

The student thinking artifact interviews were audio-recorded and ranged in length from 15 to 30 min. The artifacts were deidentified by the teacher prior to the interview. After each interview, the researcher collected and digitally scanned any artifacts discussed during the interview. Data consisted therefore of 29 digitally scanned artifacts and the corresponding teacher interview transcripts. (Note that the number of artifacts totaled more than 20, as some teachers brought and discussed more than one artifact during their interviews.)

Data analysis

In preparing our data for analysis, we coupled each artifact with the corresponding teacher interview transcript. This became our unit of analysis—an artifact and its associated teacher's talk. We coded the data along three dimensions aligned with our research questions. Two researchers (the first and third authors) independently coded the data as follows. Disagreements were discussed until consensus was reached.

To address RQ1—What do teachers identify as an artifactual representation of students' thinking in a science learning context?—we coded the data by type of artifact. That is, we examined each artifact and the associated teacher's talk and simply described what the artifact was (e.g., an entry in a science notebook, a drawing). We then looked across all descriptions and grouped them into general categories indicating the type of artifact teachers identified as demonstrating students' thinking in science. Next, to address RQ2—How do teachers describe these artifacts as representations of their students' thinking in science?—we examined interview transcripts using an inductive approach to identify key themes in teachers' descriptions of students' thinking in their artifacts. Finally, to address RQ3—In what ways are science and engineering practices evident when teachers identify and describe an artifact that shows their students' thinking in science?—we developed a convergent coding scheme (see Table 1) derived from NGSS documents as well as the extended descriptions of each of the NGSS practices elaborated further in *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012; see also NGSS Lead States, 2013).

Development of the convergent coding scheme

We used these documents particularly because in them we found distinct parallels between the work students do in a garden-based science learning context, the ways in which teachers talked about students "doing science" in a GBL context (evident in their interviews), and the *Framework*'s statement of the NGSS practices as the "the actual doing of science or engineering" (NRC, 2012, p. 42). This provided us theoretical and explanatory power in developing a coding scheme in which the NGSS practices implicit in our data (the artifacts and the teachers' talk around the artifacts) could be characterized in both a broad and nuanced way.

In developing this coding scheme we acknowledged that it would be difficult for an artifact to capture a student's engagement in an entire scientific and engineering practice, and we recognized that each broad NGSS practice consists of multiple parts. For example, the practice asking questions and defining problems can be further decomposed to indicate the type of question asked (e.g., asking questions about a phenomenon, asking questions about data, and asking questions for more information; NRC, 2012). Therefore, to capture this nuance, we developed two levels of codes, with first-order codes indicating each broad NGSS practice and second-order codes indicating nuanced components of the broader practice. Furthermore, second-order codes were only indicated for components of an individual broad practice that we might reasonably expect to see in an elementary GBL science context.

When coding the data using this coding scheme, we encountered several instances in which data could be coded with more than one practice. We decided that in these cases, the practice most predominant in the artifact and the associated teacher's talk would be designated as its code, and other secondary practices would be noted. For example, several practices were evident in the artifact in Figure 1, including planning and carrying out investigations (PCOI) and using mathematics and computational thinking. However, the practice with the strongest presence was PCOI, as the majority of this garden science notebook entry involved observations (which is a second-order code of PCOI: collect observational data [COD]), as did the teacher's talk of this artifact. Therefore, this data point would have been coded PCOI:COD.

Table 1. Coding scheme used to analyze artifacts for broad NGSS practice (first-order code) and component of the practice (second-order code).

NGSS practice (first-order code)	Component of the NGSS practice (second-order code)
AQ (asking questions and defining problems)	PH (about a phenomenon) MI (for more information) OD (about an observation in data) EP (about an engineering problem)
DUM (developing and using models)	EP (to explain a phenomenon) TSD (to test a solution or design) PO (to predict an outcome)
PCOI (planning and carrying out investigations)	IV (identify variables) DOD (determine observational data to be collected) DPF (determine procedures to be followed) PREP (prepare to implement) CTE (conduct test/experiment) COD (collect observational data)
AID (analyzing and interpreting data)	RD (represent data) UD (use data) ID (interpret data)
UMCT (using mathematics and computational thinking)	TTC (as a tool to communicate) TTT (as a tool to think)
CEDS (constructing explanations and designing solutions)	UOE (using observational evidence) USTK (using scientific theory and/or knowledge)
EAE (engaging in argument from evidence)	DMC (use data to make a claim) DSC (use data to support a claim) DRC (use data to refute a claim) BES (evaluate claims to determine the best explanation or solution)
OECI (obtaining, evaluating, and communicating information)	RCST (reading/consuming scientific texts) IST (interpreting scientific texts) PST (producing scientific texts)

Note. NGSS = Next Generation Science Standards.

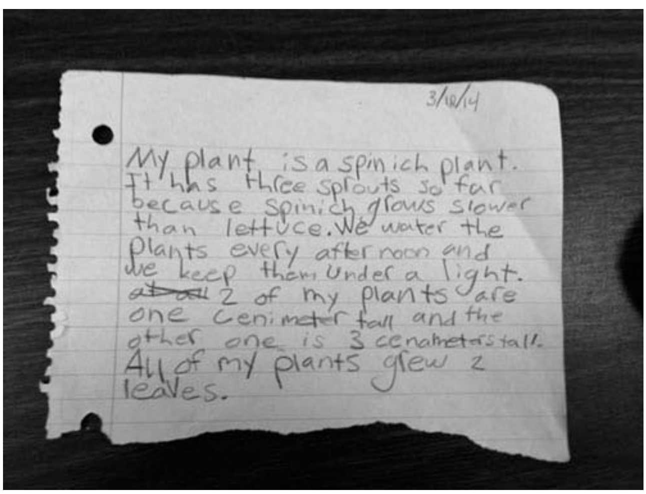


Figure 1. Artifact of a garden science notebook entry demonstrating the practice planning and carrying out investigations involving collecting observational data.

Data reduction

Because we encountered a few instances in which teachers brought more than one artifact to the interview (e.g., a whole-class set of an assignment, two different artifacts from different GBL lessons), our data set consisted of 52 artifacts. However, in order to represent the data fairly, we found it necessary to reduce the data two different ways according to the research question of concern. First, in determining what teachers identified as an artifactual representation of students' thinking in a science learning context (RQ1) we reduced the data to include one artifact representing each unique kind of artifact a single teacher brought to the interview. For example, if a teacher brought 20 garden journal entries from a single assignment/prompt, then only one entry was included in the data set, but if a teacher brought one garden journal entry and also one drawing from a different assignment/prompt, then both of these artifacts were retained in the data set. Teachers who brought only one artifact were not subject to data reduction. This data reduction strategy resulted in a data set involving 25 artifacts that were then coded according to the type of artifact they represented.

Second, in determining the ways in which science and engineering practices were evident when teachers identified and described an artifact (RQ3) we sought to identify the variety of unique first-order/second-order codes (as described previously) each teacher represented (rather than each artifact). For example, Ms. Edmund brought three artifacts, and all were retained in the data because they represented three different first-order/second-order codes. Alternatively, Ms. Murphy brought six artifacts, of which only three were retained because only three unique codes were represented among her artifacts. This reduction was necessary in order to avoid skewing the data toward overrepresenting a few first-order/second-order codes for teachers who brought more than one artifact of a similar type. To identify how many unique artifacts for a teacher, we first coded all of the artifacts (n = 52) and then reduced the artifacts accordingly (n = 29). Again, teachers who brought only one artifact were not subject to data reduction.

Results

In this section, we present the results of our analysis. We start by briefly reporting results pertaining to the first two questions of this study: the four types of artifacts teachers identified as artifactual representations of students' thinking in science (RQ1) and the primary way in which teachers consistently described these artifacts as representations of their students' thinking (RQ2). The remainder of this section focuses more extensively on results pertaining to RQ3: the ways in which science and engineering practices were evident in the artifacts teachers identified and described.

Types of artifacts

Among the 25 artifacts (based on our RQ1 data reduction) we found four general categories (or artifact types): an entry in a garden science notebook (12 instances); a piece of creative art, either visual or literary (six instances); a form of digital media (four instances); and a design of a physical object (three instances). Figure 2 summarizes this information and provides an example from the data of each artifact type. Figure 2 also includes excerpts from the interviews corresponding to each example illustrating how the teacher described the student thinking he or she saw in the artifact. We briefly discuss this result next.

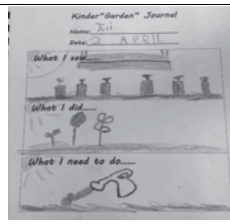
Artifact Type	# of Instances	Example	Teachers' Description of Student Thinking in Artifact
Garden Science Notebook	12		"I see a hand planting a seed in the garden. We **grew** cucumbers."
Creative Art	6		"This is something they **did** throughout the year. They had to take what they **saw** in the garden and then **bring** it in and **make** a picture."
Digital Media	4		"They **made** a video of their garden projects to **present** at the family garden night They **talk** about each one of the plants."
Design	3		"He was **picturing** and **creating** what the low tunnel would look like."

Figure 2. Artifact types, numbers of instances, examples, and corresponding teacher interview excerpts.

Teachers' description of students' thinking in the artifacts

All 20 teachers initially talked about their students' thinking, as represented in the artifacts, in terms of what their students were "doing," and 13 of the teachers continued to do so when prompted further to focus on the students' thinking that they noticed in the artifact. For example, Ms. Elliot brought a video of her students presenting their garden investigations to her interview, and when asked why she had chosen this artifact to show her students' thinking in GBL, she said, "So there are five [video] clips and each clip talks about a project that the students have done. The squash group, the blue potato group...." She then continued to describe what students did in each project. Another example of this key theme in the data is seen in Ms. Armstrong's interview when she discussed the artifact she brought (a student's tissue-paper artwork of the classroom garden) to show her students' thinking in GBL:

> This is something they did throughout the year. They had to take what they saw in the garden and then bring it in and make [a picture], I put out tissue and crayons and [said] you have to show me what you saw in the garden, because we were working on observations.

These two examples were typical of how the teachers talked about the artifact they identified as showing their students' thinking in a GBL context. Furthermore, we found that these descriptions of "doing" often contained language resembling specific scientific and engineering practices (e.g., aspects of planning and carrying out investigations, communicating information) as described in the NGSS documents that had guided our coding scheme. In other words, we found that teachers described aspects of the NGSS practices when they discussed their students' thinking in the artifacts. To be clear, we are not saying that the teachers explicitly stated or were particularly aware of this connection to the practices when they talked about their students' thinking. They simply were talking about their students' thinking that they saw in the artifacts. Our analysis revealed this similarity in language found in teachers' talk and the NGSS practices, thus providing us explanatory power in regard to what it is teachers' attend to when talking about their students' thinking in artifacts from their science teaching. Next we report on the extent to which the NGSS practices were evident in the data.

Science and engineering practices evident in artifacts and teachers' descriptions

First we present the results of our analysis by reporting the extent to which the NGSS practices in a broad sense were evident in the data. We then provide further detail of the components of the broader practices evident in the data.

Primary science and engineering practices (first-order codes) evident in the data

Five of the eight NGSS practices were coded as the primary (first-order) practices across the data. The frequency of each of these five practices varied, with planning and carrying out investigations representing the greatest frequency (13 instances out of 29; see Figure 1 for an example) and asking questions and defining problems representing the lowest frequency (1 instance out of 29). Figure 3 shows these results. Three of the broad practices were not identified as primary practices in the data and are indicated in Figure 3 with dashed lines.

Components of the broad science and engineering practices (second-order codes) evident in the data

In order to provide further detail as to the components of the broader practices evident in the data, we present the second-order code results associated with each broad practice. We do this for each of the five broad practices represented in the data and provide further examples of both artifacts and teachers' talk of those artifacts coded as such. We then describe from these findings what the teachers noticed about their students' thinking. Specifically, we illustrate what teachers attended to as they talked about students' thinking within these artifacts using these components of the broad practices.

Asking questions and defining problems (one artifact). This practice had four components (second-order codes) associated with it: asking questions and defining problems (a)

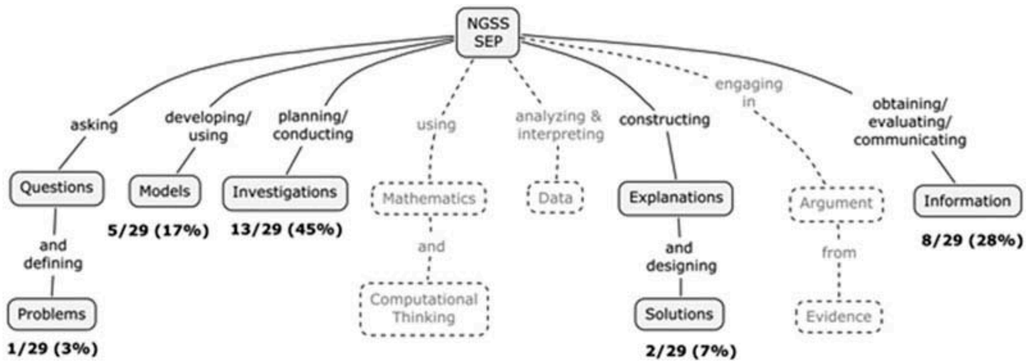


Figure 3. Primary SEPs (first-order codes) evident in the data. Dashed lines indicate the three primary practices not identified in the coded data. NGSS = Next Generation Science Standards; SEP = science and engineering practice.

about phenomena, (b) about an observation in the data, (c) about an engineering problem, and (d) for more information. Yet only one data point was coded for this broad practice, and thus only one of these components was represented in the data[2]: asking questions about phenomena. The associated artifact (see Figure 4) consisted of a science notebook entry in which a student had written questions she had about the phenomena of plant growth and survival. When discussing the student's thinking that she noticed in this artifact, Ms. Cobb pointed out that "the student came up with different questions and hypothesized about what the plants would do." In this case, then, we found that this practice, specifically the component of asking questions about phenomena, described what this teacher attended to when identifying and talking about the student's thinking that she noticed in this artifact.

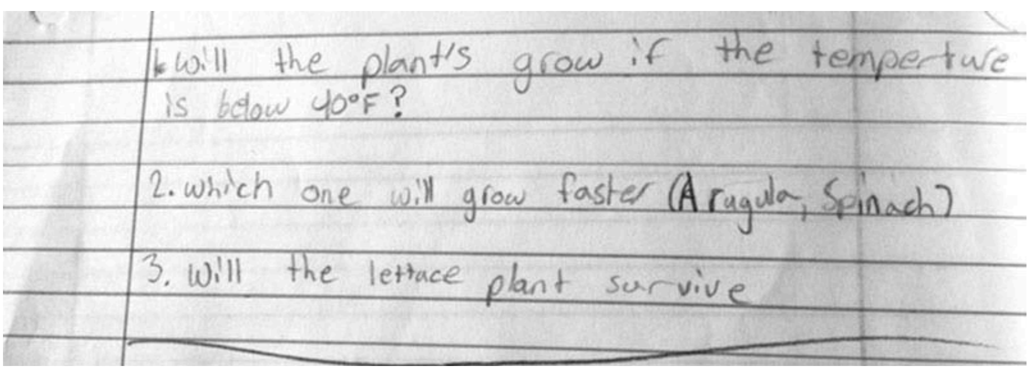


Figure 4. Artifact of a garden science notebook entry demonstrating the practice asking questions and defining problems about phenomena.

[2]The absence of the other three second-order codes in our analysis does not indicate that what teachers attended to in their students' thinking could never be described by these components of this practice, only that our data did not contain any such instances.

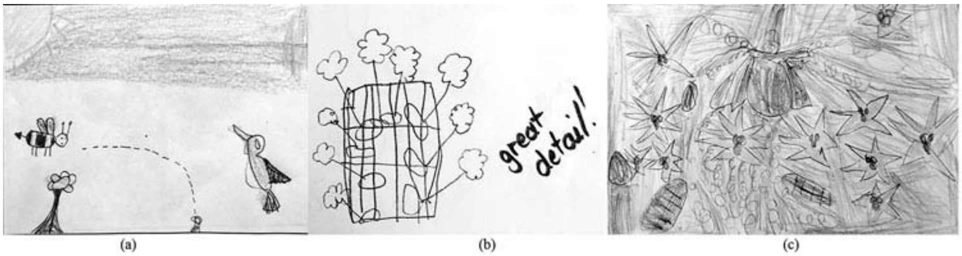


Figure 5. Three garden-based learning artifacts each representing a different component of the practice of developing and using models: (a) to explain a phenomenon (pollination), (b) to test a design (potato tower), and (c) to predict an outcome (of a recently planted cucumber garden).

Developing and using models (five artifacts). This practice had three components (second-order codes) associated with it: developing and using models (a) to explain a phenomenon, (b) to test a solution or design, and (c) to predict an outcome. All three of these components were represented in five artifacts and the associated teachers' talk from the data. These artifacts were students' illustrations involving three instances of using a model to explain phenomena, one instance of developing a model to test a solution or design, and one instance of using a model to predict an outcome. Figure 5 displays three of these artifacts, each representing a different component of the practice of developing and using models.

Figure 5a shows the component of using a model to explain a phenomenon, in this case the phenomenon of pollination. In talking about the student's thinking in this artifact, the teacher explained that students were asked to draw a picture of a pollinator, but this student did something more:

> She didn't just draw a picture of a pollinator. She tried to show the look of pollination—see the bee and the flower? She shows there is an interaction between them with this dotted line. Anybody can draw a butterfly or a bee, but this student really looked beyond the visual part of it and included in her picture what that creature's role was.

To be clear, we do not think that this illustration models the entire phenomenon of pollination, but based on the artifact itself and the teacher's talk of the artifact, we do think that the student drew a model to explain in part this phenomenon.

Figure 5b also depicts a model, however it shows a different component of this practice—developing a model to test a design. The student's drawing illustrates the design of a potato tower (a structure that supports the growth of potatoes). During her interview, this kindergarten teacher explained that the class discussed a potato tower—how it looked, what its purpose was, and so on—and then designed and constructed a potato tower to grow potatoes in the class garden. In describing the design phase of this GBL activity, Ms. Murphy explained,

> The students had worked in groups … there had been a builder, a designer, and an artist. They had to design what they needed. [Then students] were asked as their homework to talk with their parents about the potato towers and how you build them.

And then Ms. Murphy continued to describe one student's homework (see Figure 5b):

> This one shows the flowers and stems outside, potatoes were inside, and they were planted in layers. I was really impressed for kindergarten the level of detail. They were able to represent

> what they saw, and that is my goal, for them to be able to represent the model of the real thing.

These data depict the practice of developing a model to test a design because the student (with others) designed the potato tower, drew it, explained it to his parents, and finally helped construct an actual potato tower in order to support the growth of potatoes.

Finally, Figure 5c also depicts a model, but it shows a different component of this practice—using a model to predict an outcome. In talking with Ms. Walter about this artifact, we learned that it was created soon after her first graders planted cucumber seeds. She explained,

> They had to do what they thought the cucumber plant would look like after it had cucumbers on it. They had the flowers, the tendrils. She has the cucumbers. She has one vine, so all of these cucumbers come off of one plant. I think she doesn't understand that you have to have a lot of plants to get a lot of cucumbers.

So this student's drawing was not a model of the class cucumber garden at that point in time but rather her prediction of what the garden would look like in the future—that is, her model predicted that the seeds they had recently planted would grow at different rates and thus would be at different stages of growth later in the summer (i.e., some flowering, some producing fruits, etc.).

Collectively, these three artifacts and the associated teachers' talk plus two others (not shown) represented all components of the broad scientific practice developing and using models. In this case, then, we found that this practice, and even more specifically the three components of this practice, described what these teachers attended to when identifying and talking about the students' thinking they noticed in these artifacts.

Planning and carrying out investigations (13 artifacts). This practice had more components as second-order codes than the other broad practices, particularly because the practice itself encompasses two different phases of an investigation: the planning phase and the carrying-out phase. As a result, the six components of this practice involve either one or the other of these phases, not both. Table 2 lists the six components and the number of data points within this broad practice representing each component.

Thirteen of the 29 data points represented the broad practice of planning and carrying out investigations. The artifacts involved typically were part of students' garden science notebooks and included both entries prior to an investigation (planning phase) and entries made during an investigation (carrying-out phase). Other artifacts not part of a science notebook included data observation charts and photographs of students engaged in an

Table 2. Components of the planning and carrying out investigations practice and number of instances in the data.

Component of practice	Number of data points representing practice (n = 13)
Identify variables	0
Determine observational data to be collected	1
Determine procedures to be followed	2
Prepare to implement investigation	0
Conduct test/experiment	2
Collect observational data	8

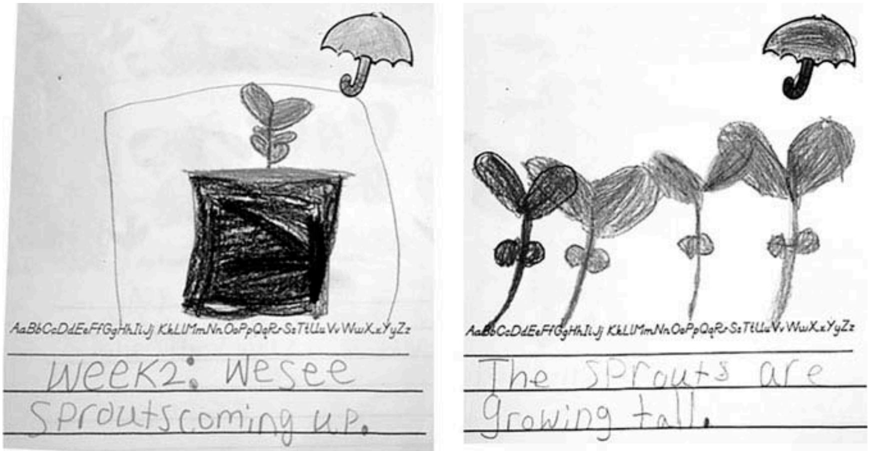


Figure 6. A first grader's sketch and description of what was observed during a plant investigation. The artifact demonstrates the practice of planning and carrying out investigations: collect observational data.

investigation. The teachers' talk of these artifacts allowed us to further identify the specific component of the broad practice of planning and carrying out investigations evident in each artifact.

As Table 2 shows, the majority of these 13 data points represented the component collect observational data (eight instances). For example, one data point involved an artifact of a first grader's sketch and description of what was observed during a plant investigation on two different days 6 days apart (see Figure 6). The drawings indicated both an observation made indoors (the sprout in a pot) and then an observation made later outdoors (the row of sprouts planted in the outside garden). In these drawings the student recorded the number of leaves as well as the increase in height over time. Furthermore, when talking about this artifact, the teacher discussed how the student's attention to detail in her drawings showed that the student knew not only how to make observations but also how to accurately record them in her notebook.

This artifact and the teacher's talk was typical of the seven other data points representing the component collect observational data. Therefore, we found that the component collect observational data of the broader practice of planning and carrying out investigations described what these eight teachers attended to when identifying and talking about the students' thinking they noticed in these artifacts.

Three other components of planning and carrying out investigations were represented by the remaining five data points coded as such (see Table 2). Three of these artifacts were produced during the planning phase of an investigation rather than the carrying-out phase, which the previous example illustrated. The artifact in Figure 7, for example, shows a student group's description of the procedures to be followed in their investigation of whether root length at the time of planting will affect subsequent plant growth. The second-grade teacher explained, "The class did an investigation to see if root length mattered. They [the students] had to think about what we would need to do this investigation and then steps that we would take to complete the investigation." The examples in Figures 6 and 7 as well as the 11 other data points representing this practice

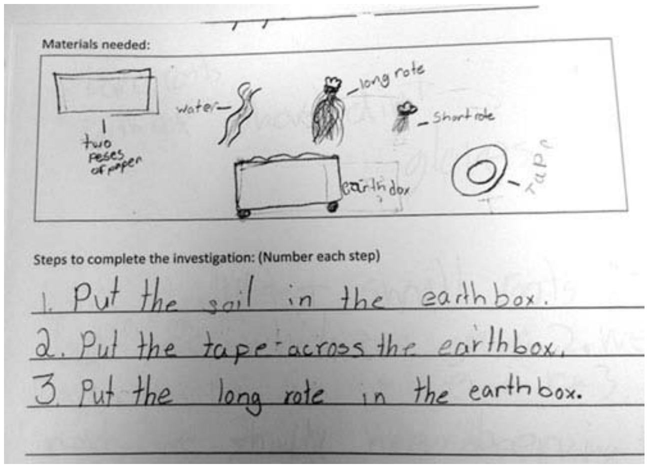


Figure 7. Artifact representing the practice of planning and carrying out investigations: procedures to be followed. A group of second graders described the procedures to be used in their investigation of whether root length at the time of planting will affect subsequent plant growth.

and its components show that teachers attended to students' thinking connected to both planning and carrying out investigations, but the artifacts teachers identified as representing their students' thinking more often revealed components of the carrying-out aspect of this practice.

Collectively, these 13 artifacts and the associated teachers' talk represented four of the six components of the broad scientific practice planning and carrying out investigations. This practice, and more specifically the four components of this practice seen here, was most frequently represented among the 29 data points; thus, we found that teachers attended to their students' thinking surrounding this practice more than others as evidenced in the artifacts they identified and discussed as representing their students' thinking in science.

Constructing explanations and designing solutions (two artifacts). This practice had two components (second-order codes) associated with it: using scientific theory and/or knowledge and using observational evidence. Both of these components were evident one time each in our data (see Figures 8 and 9).

Figure 8 shows an artifact from our data representing the practice of constructing explanations and designing solutions using scientific theory and/or knowledge. A kindergarten student created this artifact to explain to her parents how to plant potatoes using a potato tower. In her interview, Ms. Murphy explained that this artifact was produced as homework after a whole-class discussion about growing potatoes in which students explored and discussed various gardening websites to see, discover, and discuss how they could grow potatoes in their garden. When asked about the student's thinking she saw in the artifact, Ms. Murphy explained that "it [the artifact] wasn't as we were doing it in class during the activity, it was from her memory [of the whole-class discussion] ... and this child shows what we need, the steps, and a list of how to plant potatoes." This artifact was one of several shared by Ms. Murphy of the same potato tower homework assignment

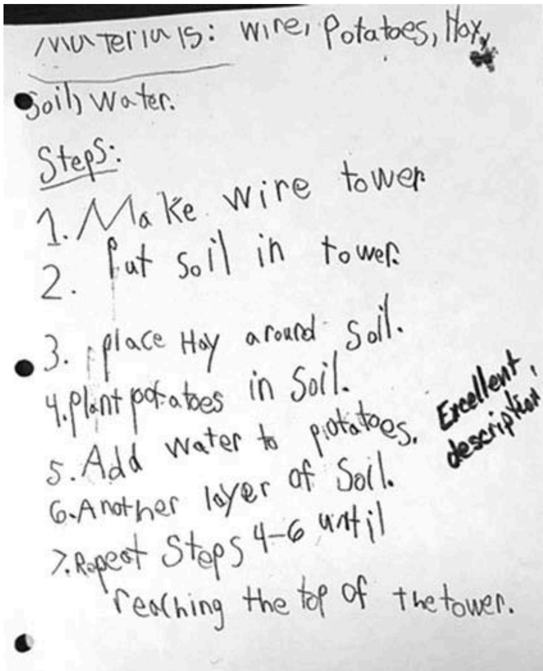


Figure 8. Artifact representing the practice of constructing explanations and designing solutions: using scientific knowledge. A kindergarten student created this artifact to explain to her parents how to plant potatoes using a potato tower.

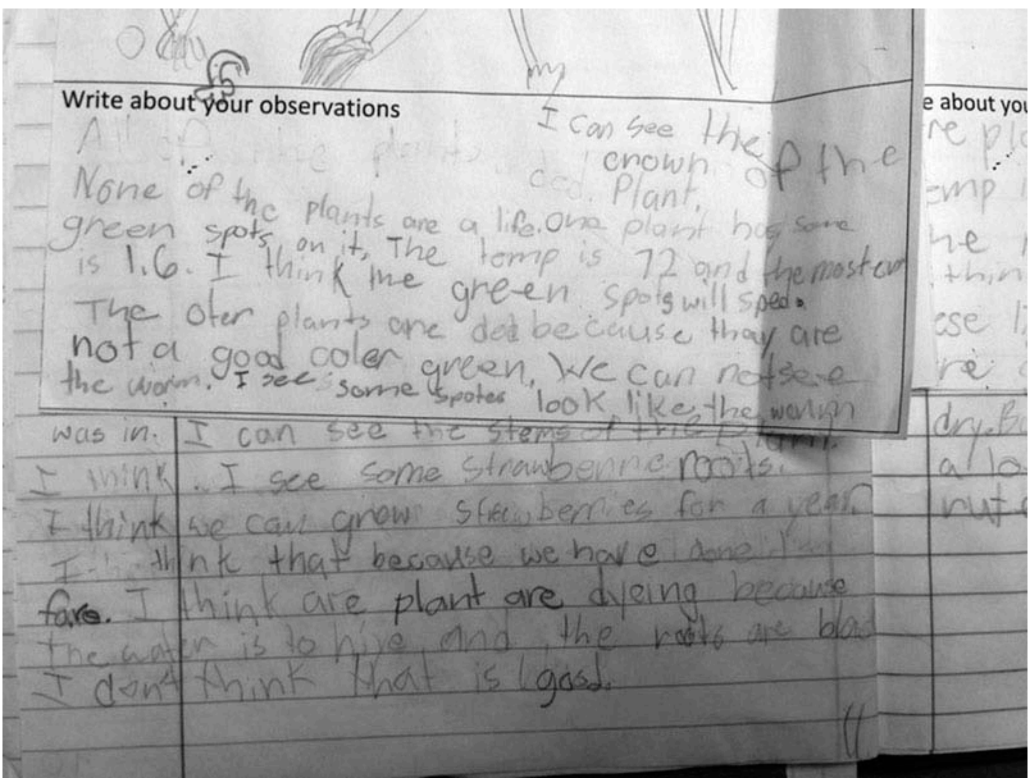


Figure 9. Artifact representing the practice of constructing explanations and designing solutions: using observational evidence. In this artifact, a second-grade student offered an explanation tied to her observations of the appearance of strawberry plants.

(e.g., see Figure 5b). Even though both artifacts in Figures 5b and 8 were from the same homework assignment, they each had a unique code because the predominant practice evident in the data differed across these two artifacts. As discussed previously, the artifact in Figure 5b represented the practice of developing a model to test a design, whereas the artifact discussed here (in Figure 8) represented more strongly the practice of constructing an explanation using scientific knowledge of how to grow potatoes using a potato tower—here the student drew on knowledge from her exploration of gardening websites during the class discussion to explain to her parents how to grow potatoes. Thus, even among artifacts resulting from the same assignment, the teacher attended to different aspects of her students' thinking. Specifically, as related to the practice of constructing an explanation using scientific knowledge (gleaned from the whole-class discussion), we can see that in this case Ms. Murphy attended to the student's thinking around her explanation of what potatoes need to grow (materials) and how to grow potatoes (steps) evident in this artifact.

Another artifact (see Figure 9) and the associated teacher's talk also represented the broad practice of constructing explanations and designing solutions, but this data point depicted the other component of this practice—using observational evidence. This artifact showed a student's entry in a garden science notebook in which she had recorded specific observations of strawberry plants. This data point was coded as constructing explanations using observational evidence because in the artifact the student offered an explanation tied to her observations of the appearance of some of the plants. For example, the student used observations to explain why the plants looked the way they did. First, she indicated that "the other plants are dead because they are not a good color green"; then, she explained that even though she cannot "see the worm," she can "see some spots that look like the worm was in [on the plant]." Finally, she said that "the plants are dying because the water is too high and the roots are black. I don't think that is good."

In addition, in her interview, Ms. Millbank talked both generally about how she expected students to explain their observations and also specifically about this student's explanation and evidence of why the plants were dying:

> If they [students] said one of the plants was dead, they had to say why they think it's dead. They had to provide evidence, like the leaves were brown or laying on the ground. [In this artifact] I notice that she is thinking about the colors of the leaves and she thinks that something might have eaten them because she noticed that our soil has worms.

In these two data points, then, we found that the practice of constructing explanations and designing solutions, and even more specifically the two components of this practice, described what these teachers attended to when identifying and discussing their students' thinking evident in the artifacts—that is, teachers attended to the aspects of the students' explanations that drew on scientific knowledge in one case and on observational evidence in the other case.

Obtaining, evaluating, and communicating information (eight artifacts). This practice had three components as second-order codes: (a) producing scientific texts, (b) interpreting scientific texts, and (c) reading and consuming scientific texts. Eight of the 29 data points represented this broad practice and two of these components. The eight artifacts themselves included many different kinds of artifacts, including multimedia and video

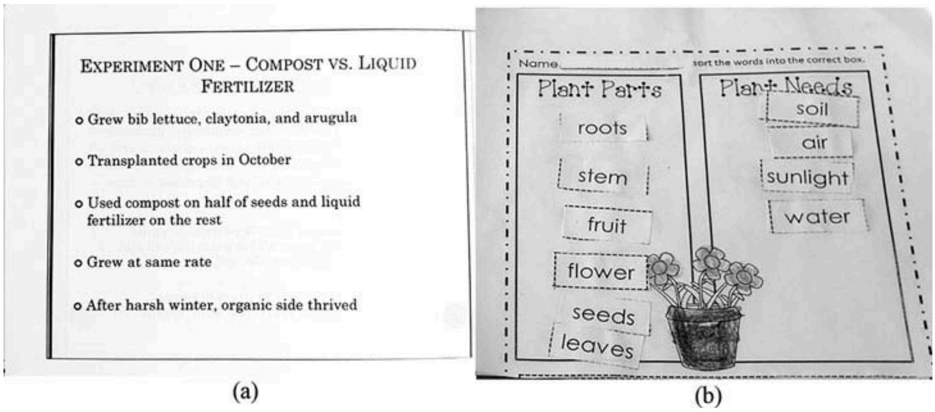


Figure 10. Two garden-based learning artifacts each representing a different component of the practice of obtaining, evaluating, and communicating information: (a) producing scientific texts (student-created slide presentation of a scientific investigation) and (b) interpreting scientific texts (student categorization of plant parts and plant needs from text provided by the teacher).

presentations, posters, pamphlets, garden notebook entries, and a fictional story. Figure 10 provides two of these artifacts showing the different components of this broad practice represented in the data.

Six of these eight artifacts and associated teacher's talk represented the component of producing scientific texts of this broad practice. For example, Figure 10a shows an artifact of a scientific text (a slide presentation) that was produced by a fifth-grade class investigating the effects of using organic (compost) or conventional (liquid fertilizer) methods in growing different lettuce greens. In discussing the students' thinking in this artifact, Ms. Wilson talked about how the presentation was developed and shared with others at an evening open-house-type event in which the school's GBL program was showcased:

> First they [the students] did research, then they did a debate, and then they wrote a persuasive paper. They pulled excerpts from their persuasive papers for this presentation, and a few of my students presented it to parents and other [community visitors] at the garden night.

This artifact, then, was considered a scientific text in that it was produced in order to communicate the investigation—what was learned through research and experimentation—to others outside their classroom community. This kind of artifact and the associated teacher's talk was typical of this component—students producing a text (i.e., a video, a poster, etc.) in order to communicate their GBL investigations to others.

The other two data points that represented the broad practice of obtaining, evaluating, and communicating information involved the second-order component of interpreting scientific texts. Figure 10b shows an entry from a garden notebook that shows how a first grader categorized "plant parts" and "plant needs" from text provided by the teacher. In her interview, Ms. Yarrow talked about this artifact as involving an activity in which students both obtained and interpreted information that would help them later in their indoor GBL investigation:

> I brought this artifact because it shows a scaffolded thing we did. We talked about the plant parts, and we talked about what the plants need to survive because I thought that was

> important for them to know before we planted so that they would know that even though we are growing them [our plants] inside we still need a source of light, we still need water, still need soil, all those things.

Collectively, the artifacts in Figure 10 and the associated teacher's talk plus six others represented two of the three components of the broad practice obtaining, evaluating, and communicating information. The remaining component—reading and consuming scientific texts—was not present in the collected data. This is not surprising, because it seems unlikely that a teacher would have an artifact, such as a picture of a student reading, that would represent him or her attending to this component. In this case, then, we found that this broad practice, and even more specifically the two components of this practice seen in the data, described what these teachers attended to when identifying and discussing their students' thinking evident in the artifacts.

Discussion

In this study, we investigated what teachers notice about students' thinking in artifacts produced in their science learning context—more specifically, we investigated the attending aspect of teacher noticing as teachers discussed their students' thinking in GBL artifacts. Our initial analysis found that when asked about their students' thinking evident in an artifact, all of our teachers described what their students were "doing" in producing that artifact. Our subsequent analysis further unpacked these descriptions of student activity and found that when asked to identify and discuss their students' thinking evident in the artifacts, teachers used language that closely resembled the scientific and engineering practices of the NGSS. Therefore, from this we were able to describe the ways in which teachers attended to their students' thinking surrounding these practices. We contend that this is an important aspect of these teachers' noticing. In what follows, we further discuss this kind of noticing and the implications of this work for teacher learning. We conclude with future research considerations.

First, our results showed that five of the eight NGSS practices were represented in the artifacts teachers identified as showing their students' thinking in GBL and their talk surrounding these artifacts. This suggests that engaging students in the NGSS practices in an authentic science learning context may involve the production of artifacts that provide teachers with a window into students' thinking in science. Furthermore, the fact that nearly half (45%) of the artifacts in this study represented the practice of planning and carrying out investigations suggests that engaging in this practice perhaps even more so produces artifacts that explicitly display aspects of students' thinking and are thus an important tool for teachers in noticing students' thinking in science. We found it noteworthy that not only did our teachers find these artifacts useful in showing their students' thinking (as evidenced by the fact that they chose such artifacts to represent their students' thinking in GBL), but they also described students' thinking in the artifacts in terms of the activity surrounding the NGSS practices (e.g., students "recorded observations of their cucumber plants," "measured how many centimeters their plants grew each week," "sketched out a design of a potato tower"). This suggests that teachers may at times understand that attending to their students' thinking means attending to what students are doing associated with the practices—in other words, teachers may notice students' activity as a component of students' thinking in science.

Second, our results showed that three of the eight NGSS practices—using mathematics and computational thinking, analyzing and interpreting data, and engaging in argument using evidence—were not represented in our data. As discussed previously, we did see evidence of the practice using mathematics and computational thinking in our data, but it was never the primary practice teachers identified as representing their students' thinking, and therefore none of the data points was coded as such. More important, however, we find the total absence of the remaining two practices quite interesting and offer two possible explanations for this finding. This absence might suggest that engaging students in some NGSS practices may not involve the production of artifacts that explicitly show students' thinking surrounding that practice. In fact, we saw this with one of the subcomponents of the obtaining, evaluating, and communicating information practice absent from our data—reading and consuming scientific texts. (As we discussed earlier, we would not expect teachers to identify artifacts that show students reading textbooks as representing their students' thinking in science.) However, we think the two practices absent in our data could reasonably result in artifacts that show students' thinking surrounding those practices. Engaging students in analyzing and interpreting data, for example, could result in an artifact of a data table with text identifying patterns in the data or statements describing patterns seen and what those patterns indicate. Also, engaging students in argument using evidence could result in a video artifact of a class discussion in which different claims are offered and supported. Therefore, we suspect that this is not the reason for the absence of these practices in our data. Alternatively, it might be that our teachers, although they had such artifacts, simply did not choose to bring artifacts representing these practices to their interviews. Perhaps this is the case, but we think it is not, and we worry that these practices were absent because teachers did not engage students in these practices in their GBL context and therefore students did not produce artifacts representing such in which to notice students' thinking in science. We find this troubling because the thinking surrounding these two practices is quite important in students forming coherent understandings of scientific phenomena (NRC, 2007, 2012). If teachers do not engage students in these practices, artifacts providing a window into students' thinking will not result, and thus students' thinking will remain hidden.

Finally, our results indicated that teachers chose one type of artifact most often to represent their students' thinking in science. Twelve of the 25 artifacts (or 48%) included in our analysis were students' garden science notebook entries. We find this quite interesting in that the prevalence of a single type of artifact both focused and limited our teachers' noticing of students' thinking surrounding the NGSS practices. The garden science notebook entries were varied in what they contained, including drawings, data tables, written text, and so on, and spanned the full range of the NGSS practices and their components represented in our data. This suggests that science notebook entries in particular may have focused teachers' attending to aspects of students' thinking around specific components of a broad NGSS practice because these artifacts were often produced in the midst of engaging in activity surrounding a specific component of a practice. For example, eight out of the 29 artifacts in our RQ3 data set were coded as instances of planning and carrying out investigations: collect observational data. This suggests that these teachers found records of observations of phenomena representative of their students' thinking in science. Furthermore, the fact that these eight artifacts represented 28% of the data suggests that this specific component of planning and carrying out investigations resonated rather strongly with these teachers as something to be noticed about students' thinking in a science notebook entry. However, although a particular type of artifact (such as a science notebook entry) can focus teachers' attention to students' thinking surrounding specific components of the practices, an emphasis on one type of artifact may also limit teachers' attending to students' thinking surrounding other components of specific NGSS practices. For example, the practice of planning and carrying out investigations encompasses two different phases of investigation: the planning phase and the carrying-out phase. In our coding scheme, this broad practice was further decomposed into six relevant components (second-order codes; see Table 2), with four of these components involving the planning phase and two involving the carrying-out phase. Our results indicated, however, that teachers' attention to students' thinking was primarily focused on that surrounding the carrying-out components and not the planning-related components of this broad practice. In other words, teachers did not very often see students' thinking surrounding rather important activity in planning an investigation, and perhaps this is because their chosen artifacts (primarily garden science notebook entries) did not show students' thinking around planning their investigations. To be clear, we are not saying that science notebook entries cannot show this thinking, only that our teachers did not attend to the thinking surrounding the planning components of this broad practice. Therefore, although a single type of artifact can focus teachers' attention on students' thinking surrounding a particular practice, it is important to note that it can also limit what is noticed.

Conclusion

Building on the work of teacher noticing in science, this study provides a snapshot of teachers' noticing of students' thinking surrounding the scientific and engineering practices of the NGSS. Prior work examining teachers' noticing of students' thinking in science has generally focused on teachers' attention to the thinking surrounding specific disciplinary content (e.g., Alonzo & Gearhart, 2006; Black et al., 2003; Covitt et al., 2014; Furtak, 2012; Furtak & Heredia, 2014). This general focus is noteworthy in that it informs reform-oriented science teaching practices, curriculum, teacher education, and professional development around the most current thrust in reform of K–12 science education in the United States—the implementation of the NGSS. Successful implementation of the NGSS involves teaching science in ways that support students' learning around disciplinary core ideas, crosscutting concepts, and scientific and engineering practices—the three dimensions of the NGSS. Yet this prior work on teachers' noticing of students' thinking in science emphasizes attention to students' thinking surrounding primarily two of these dimensions—disciplinary core ideas and crosscutting concepts—and generally does not examine teachers' attention to students' thinking surrounding the third dimension—science and engineering practices. By examining teachers' attention to students' thinking surrounding this third dimension, this study addressed this gap in the research.

Therefore, the results of this work certainly have important implications for both studying and supporting teachers' noticing of students' thinking around the scientific and engineering practices of the NGSS. This study demonstrates that teachers' choice of artifacts and subsequent discussion of such artifacts can provide researchers insight into how teachers understand what it means to notice their students' thinking in science. In particular, this study shows that the third dimension of the NGSS—the scientific and engineering practices—is certainly an important aspect of teachers' noticing of students' thinking in science that manifests itself as attention to what students are doing in science learning contexts. We understand science practices as involving "doing something and learning something in such a way that the doing and learning cannot really be separated," as stated in *Ready, Set, Science! Putting Research to Work in K-8 Science Classrooms* (Michaels, Shouse, & Schweingruber, 2008, p. 34). Perhaps the results of this study can be interpreted in a similar manner, in that these teachers understand that what students are doing and what students are thinking cannot really be separated. This study demonstrates that attending to what students are doing is one way teachers pay attention to students' thinking in science. The fact that certain practices and their related components were evident in the artifacts teachers chose to represent their students' thinking in this study provides explanatory power for how teachers attend to their students' thinking in a GBL science context. Furthermore, the practices not evident in our data also reveal something about teachers' attention to students' thinking, indicating either what could not be seen in artifacts or what was not attended to in this research context—both of which are important to understanding teachers' noticing of students' thinking in science. Further research is needed to clarify why some practices were present while others were absent in our findings.

By revealing this important aspect of teacher noticing, this study helps us more fully understand and therefore better support this construct of teacher thinking in science teaching contexts. For example, this study suggests a tendency among teachers to focus on what students are doing when they are asked to notice their students' thinking in science. Essentially, for the teachers in this study, doing and thinking are intricately connected in science learning. This raises the question of how to leverage this tendency as teachers learn to teach in ways that emphasize the three-dimensional nature of thinking in science. Furthermore, this also raises the question of how to help teachers include those aspects of doing that were notably absent from the noticing described in this study (e.g., analyzing and interpreting data, engaging in argument using evidence). More research involving the design of teacher professional development and teacher education experiences is needed here. Such design-based research should be informed by the findings of this study and utilize artifacts from science learning contexts to support teachers in learning to notice students' thinking as they engage in all of the NGSS practices. For example, one such future line of inquiry could build from this current study by asking students directly about their thinking evident in artifacts. We think this would be an interesting and important line of inquiry to pursue in studies of teacher noticing because such research could also inform the design of teacher learning that uses artifacts as well as students' voices as a means of focusing teachers' noticing on the three-dimensional nature of students' thinking in science that is hidden and embedded in those artifacts. Ultimately, we imagine professional development and teacher education experiences that leverage teachers' tendency to focus on what students are doing in science, utilize artifacts from authentic science learning contexts, and incorporate students' explanations of their thinking evident in artifacts as a means of comprehensively noticing students' thinking across all three dimensions of the NGSS.

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