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Moving Beyond "Hands-On" Instruction: Preservice Elementary Teachers Focusing on Sensemaking

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ABSTRACT

In our elementary science methods courses, we aim to shift our preservice teachers' view of science instruction beyond teacher-directed, hands-on "touching and telling," toward a student-centered approach that emphasizes scientific sensemaking. To that end, we have been emphasizing the sensemaking nature of the eight science and engineering practices (SEPs) defined in the Next Generation Science Standards. In this study, we investigated the question: What happens when we ask preservice elementary teachers to explicitly attend to sensemaking as they plan for and reflect on their own science teaching? By analyzing their written lesson planning and reflection documents, we found that: (a) they attended to both the material and intellectual work associated with sensemaking, but didn't explicitly distinguish between the two, (b) they attended to sensemaking occurring at various "grain sizes," and (c) some of them improved, refined and/or deepened their understanding of how the various SEPs are used for different kinds of sensemaking as they shifted from the planning process to the reflecting process. Our findings demonstrate that with proper support, preservice teachers are capable of understanding that elementary science instruction can and should move beyond fun, hands-on science activities, in order to engage students in scientific sensemaking.

KEYWORDS

Elementary science methods; preservice teachers; science practices; sensemaking

A major goal of the current wave of science education reform (e.g., National Research Council, 2012; NGSS Lead States, 2013) is to engage students in "making sense of the natural and designed world by engaging in science and engineering practices" (Schwarz et al., 2017, p. 4). Yet, a decade after the publication of the *Next Generation Science Standards*, a "hands-on" approach persists as the dominant narrative of what constitutes high-quality science instruction, with little understanding of how a hands-on experience can be used to support student sensemaking (Furtak & Penuel, 2018). At the elementary level, the "hands-on" approach typically emphasizes teacher-directed procedures for students to follow, that require little to no intellectual work on the part of the science learners (as opposed to student-centered scientific sensemaking). We refer to this approach as "touching and telling" (Ricketts, 2024)—the kids are touching some hands-on materials as the teacher tells them the science ideas they are supposed to be learning. In other words, the students are engaging in the material work of the lesson, while the teacher is responsible for the intellectual heavy lifting.

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In addition to supporting in-service elementary teachers with sensemaking-oriented curricula, assessments and professional learning opportunities, we believe it is critical for preservice elementary teachers (PSETs) to develop an understanding of sensemaking. We hope to support shifts in their thinking about the purpose of the hands-on experience and their view of how students learn important science ideas. Specifically, we aim for them to: 1) view the purpose of the hands-on experience as giving students a collective opportunity to experience and make sense of a real-world natural phenomenon, and 2) value sensemaking as a powerful way to learn science. In this article, we describe how this work unfolded with a cohort of PSETs as they used the lens of sensemaking to engage with elementary science curriculum and reflect on their own science teaching. We contribute to the growing number of studies of PSETs learning to engage students in sensemaking (e.g., Arias & Davis, 2017; Bismack et al., 2022; Dalvi et al., 2021; Zembal-Saul, 2009), by bringing an empirically rich account to the field in response to the research question: *What happens when we ask preservice elementary teachers to explicitly attend to sensemaking as they plan for and reflect on their own science teaching?* Our goal is to highlight how the PSETs thought about sensemaking and how they responded to tasks designed to support that thinking, to help our fellow science teacher educators be intentional about the language and tasks they use with PSETs as they work toward similar goals.

Literature review

We ground our study in theoretical constructs of sensemaking, science practice-readiness, using tools to support preservice teacher learning, and we draw from existing research on PSETs' learning about SEPs and sensemaking. At the conclusion of this section, we describe how this literature framed our pedagogical and research goals and methods.

Sensemaking via the science and engineering practices

Addressing a need to bring clarity to sensemaking as a theoretical construct in the literature, Odden and Russ (2019) define sensemaking as "a dynamic process of building or revising an explanation in order to 'figure something out'—to ascertain the mechanism underlying a phenomenon in order to resolve a gap or inconsistency in one's understanding" (p. 191). Sensemaking engages students in both material and intellectual work. Material work involves using the senses and one's body to interact with the world, typically manipulating physical (or virtual) materials and artifacts (Otrel-Cass & Cowie, 2019). The intellectual work of sensemaking refers to the cognitive processes in which learners actively construct knowledge. Odden and Russ (2019) distinguish the epistemological framing of the intellectual work of sensemaking from other kinds of intellectual work that would not be characterized as sensemaking, such as memorizing, recalling, or "answer-making" (Chen et al., 2013), where students aim to "produce a canonically correct answer, regardless of whether it fits with their understanding" (Odden & Russ, 2019, pp. 193–194). Drawing on perspectives of embodied cognition, which hold that "cognitive processes are deeply rooted in the body's interaction with the world" (Wilson, 2002, p. 625), we recognize that the material work and intellectual work of sensemaking are intertwined, and thus not easy to disentangle, analytically. We also acknowledge that sensemaking in the science classroom includes other

Table 1. Science and engineering practices for K-12 science classrooms (NRC, 2012, p. 42).

SEP #	Practice Name	Discipline(s)
1	Asking questions	Science
	Defining problems	Engineering
2	Developing and using models	Science & Engineering
3	Planning and carrying out investigations	Science & Engineering
4	Analyzing and interpreting data	Science & Engineering
5	Using mathematics and computational thinking	Science & Engineering
6	Constructing explanations	Science
	Designing solutions	Engineering
7	Engaging in argument from evidence	Science & Engineering
8	Obtaining, evaluating, and communicating information	Science & Engineering

kinds of "work" related to using discourse practices within a community of learners (Davis et al., 2020).

Building on Odden and Russ's (2019) definition, Davis et al. (2020) characterize sensemaking in science as occurring "*through* authentic engagement in science practices, including the discourse they entail" (p. 1, italics original). Here, Davis et al. (2020) refer to the set of eight science and engineering practices (SEPs) defined by the National Research Council (NRC, 2012, see Table 1). These SEPs characterize the various ways that K-12 students should engage in scientific sensemaking in the classroom and are "based on an analysis of what professional scientists and engineers do" (NGSS Lead States, 2013, p. 49). Note that in this study's data, the participants frequently refer to these practices by the numbers in Table 1 (e.g., "Developing and using models" is referred to as "SEP 2").

Science practice-readiness

Learning to teach is a complex process. Novice teachers develop initial understandings of various aspects of teaching that later serve as building blocks for more in-depth and interconnected understandings of and competencies for teaching (Davis & Smithey, 2009). In this article, we draw on the notion of "readiness" for teaching, in which these building blocks are viewed as "a place from which preservice teachers begin their journey towards becoming well-started beginners" (Haverly & Davis, 2024, p. 77). The teacher education literature identifies multiple kinds of readiness for teaching, including Pedagogical Content Knowledge-readiness (Smithey, 2008), and more recently, science practice-readiness, which Bismack et al. (2022) define as the "initial understandings of the science practices and how to teach them that can serve as entry points into more developed, interconnected understandings" (p. 379).

Bismack et al. (2022) identify multiple dimensions of science practice-readiness, including the notion that "students should be the ones engaging in the intellectual work of the science practices, and not the teacher" (p. 364). They further argue that mastering this particular dimension of science practice-readiness, "may serve as a 'foot in the door' for knowing how to engage students in those science practices" and allow novice teachers "to build on this understanding to strengthen their knowledge of other dimensions of the science practices" (Bismack et al., p. 379). We concur, and put forth that understanding the (student) intellectual work of the practices is potentially the most critical dimension of science practice-readiness for PSETs to develop, so that they can begin to move beyond "touching and telling" in their own science teaching, toward facilitating their students' sensemaking. Thus, in our study, we focus on this dimension. We hope to contribute to the literature around this novel construct, expanding empirically on the construct of science practice-readiness. To date, no other research has done so.

Using tools to support preservice teacher learning

Teacher educators commonly use a wide variety of tools to support learning in preservice teacher education contexts. By "tools" we mean material objects designed to support users "to accomplish a task that they would not be able to do independently" (Fick & Arias, 2017, p. 4). Contemporary research in preservice teacher education has provided evidence for the usefulness of tools for: engaging in the practices of Ambitious Science Teaching (Windschitl et al., 2012); planning model-based instruction (Téllez-Acosta et al., 2024), noticing and analyzing "student thinking and scientific practice use" (Benedict-Chambers & Aram, 2017); planning for equitable student sensemaking (Benedict-Chambers & Sherwood, 2024); aligning instruction with the Next Generation Science Standards (M. L. Sinapuelas et al., 2019). Tools embody knowledge, and thus have the potential to help preservice teachers "notice and interpret critical features of science instruction" (Benedict-Chambers, 2016, p. 39), including "what to attend to and how to make sense of students, learning, and methods of teaching so that teachers can continue to learn in and from practice" (Chung & Van Es, 2014, p. 114). By studying their use of 32 different tools with PSETs, Fick and Arias (2020) articulated a theory of action for how tools support PSETs' learning. Specifically, tools make implicit features of teaching explicit "through limiting options, breaking down the practice into obvious steps, or requiring consideration of the how or why involved in the practice" (p. 133). In our study, we used a "SEP Tool" (described in the Methods section) to make the implicit intellectual work of the SEPs more explicit for PSETs, which we hope will expand the literature around using tools to support PSETs' learning.

PSETs' attention to the intellectual work of the SEPs

A growing body of literature has investigated PSETs learning about the SEPs. This literature includes a wide range of foci, including: PSETs' ideas or knowledge about the individual SEPs or the SEPs collectively (Bennion et al., 2022; Fackler, 2025; Ricketts, 2014; Subramaniam, 2023; Zangori & Forbes, 2013); PSETs' engagement in the SEPs as science learners (Bennion & Davis, 2024; Smith & Anderson, 1999); the ways PSETs engage their students (typically in field experiences) in the SEPs (Boyer, 2016; Zangori & Forbes, 2013; Zembal-Saul, 2009). Very few studies explicitly investigate PSETs' understanding of the intellectual (and not just material) work that elementary students (rather than teachers) should be doing while engaging in the SEPs (e.g. Arias & Davis, 2017; Bismack et al., 2022; Dalvi et al., 2021). We identify our study as situated in conversation with this latter subset of the literature, which we review here.

Dalvi et al. (2021) analyzed PSETs' responses to a Curriculum Critique and Revision (CCR) task at the end of a semester-long methods class, and found that the PSETs largely viewed the SEPs as "restricted to students following teacher-designed procedures and answering teacher questions" (p. 141). Likewise, in Arias and Davis's (2017) study of PSETs across two years of their preservice teacher education programs, most of the PSETs did "aspects of the intellectual work [of analyzing and interpreting data, and constructing evidence-based claims] for students throughout the program, although this declined slightly over time" (p. 213). In contrast, the "novice" elementary teachers that Bismack et al. (2022) studied across two years of their preservice teacher education program and first two years of inservice teaching, "demonstrated a strong understanding [across all SEPs] that students should be the ones engaging in the intellectual work of the science practices, and not the teacher" (p. 364). Similarly, Benedict-Chambers and Sherwood (2024) found that PSETs regularly attended to strategies in lesson plans that could "engage students in authentic scientific work focused on investigating and explaining phenomenon" and "position students as knowers" (p. 862). Interestingly, these same PSETs were less successful at attending to other aspects of sensemaking in their lessons, such as explicitly leveraging students' lived experiences and facilitating equitable engagement and participation (Benedict-Chambers & Sherwood, 2024). In all of these studies, the science methods course (or overall program) focused heavily on supporting students' engagement in the SEPs. The variation across their findings documents the ongoing challenges of supporting PSETs as they learn to teach science as facilitating students' scientific sensemaking.

Framing the study

Drawing on this literature, PSETs need thoughtfully designed experiences that develop their readiness for learning to teach science as facilitating student sensemaking. Specifically, these experiences should support PSETs' understanding that: a) sensemaking requires both intellectual and material work, b) in science, the SEPs serve as the vehicles for that sensemaking, and c) studentsnot teachersshould be the ones engaging in the SEPs. To put these understandings into practice, PSETs need experiences planning for, teaching, and reflecting on science lessons that engage their students in both the material and intellectual work of sensemaking, which may be supported by a variety of tools. Through these experiences, they may begin to recognize the power of teaching science with a focus on sensemaking, and be ready to start moving beyond a hands-on, "touching and telling" approach with their future students. In the next section, we describe what these learning experiences looked like in the context of the study, and how we investigated the PSETs' attention to sensemaking.

Methods

Methodology

We designed this investigation as a qualitative case study. Yin (2009) defines case study as "an empirical inquiry that investigates a contemporary phenomenon in-depth and within its real-life context, especially when the boundaries between the phenomenon and context are not clearly evident" (p. 18). Here, the PSETs' ideas about sensemaking are inseparably embedded within the particular context of their methods classroom and field experiences, making case study an appropriate methodological design for this inquiry. In this study, we define our "case" as a cohort of PSETs learning to teach science as facilitating students sensemaking, via a specially designed methods class and field experience. Below we delineate the essential details of our participants, the methods course and program they were enrolled in, and the specific activities that generated our data, in order to sufficiently define our case and contextualize our findings.

Participants and context

The participants in this study were 23 PSETs enrolled in a one-year, post-baccalaureate, multiple subject teaching credential program at a large university on the west coast of the United States. The program used a "residential" cohort model where the PSETs enrolled in cohort-specific sections of their methods classes, and a year-long student teaching field experience, designed to provide them with opportunities to immediately practice what they learned in their methods courses in real elementary classrooms. Cohort members were placed in one of two schools in the same school district, which had "hosted" the program for several years. Although no two schools are identical, these two schools were quite similar in many ways, and they used the same elementary science curriculum. Thus, we bounded the case as the full cohort, rather than as two separate school-based cases. The study took place during the first semester of the program, when the PSETs were taking the science methods course together. In this first semester of student teaching, the PSETs were placed in classrooms together in pairs, in order to learn with and from each other. For the purposes of anonymity, we refer to each PSET by a letter, e.g., "PSET R, PSETs A & B." Amy (Author 1) served as the instructor for the science methods course.

The methods course heavily emphasized an approach to science instruction as engaging students in scientific sensemaking. Participants read about, engaged in, and reflected on sensemaking throughout the semester. Initial readings (e.g. Schwarz et al., 2017) focused on the "big picture" of sensemaking (and how it differs from "hands on"), followed by readings and activities focusing on the SEPs and how they are used for sensemaking (e.g., Pasley et al., 2016). Across the semester, the PSETs frequently used a set of tools known as the Next Gen ASET Science and Engineering Practices Tools ("SEP Tools"). As part of the Alliance for Science Educators Toolkit (ASET, 2015), the SEP Tools were developed to scaffold K-12 teachers' examination of science curriculum and/or teaching practices, support discourse around how the SEPs are being enacted in classrooms, and foster closer attention on what students (and not just teachers) are doing. The SEP Tools subdivide each practice into discrete and digestible components meant for easy access and application to lesson/unit planning, and preparing precise learning objectives (M. L. S. Sinapuelas et al., 2018).

The SEP Tools are structured in a two-page format (See the Appendices 1 and 2 for one example or nextgenaset.org/ngss/aset-toolkit/ for the complete set). The first page of each SEP Tool provides a short description of the practice, a list of the components of that practice, a yes/no column for users to indicate whether that component is present in a lesson, and columns where users can describe the teacher and student actions that match the component. The second page of each SEP Tool describes the specific details of each component in a particular grade band(s). These grade band descriptors reveal the complexity of each SEP, providing characteristics of the practice as it is used by students in grades K-2, 3–5, 6–8, and High School. For example, perhaps a teacher at the K-2 grade level wants to focus their students on the practice of Analyzing and Interpreting Data (see Appendices 1 and 2 for this SEP Tool). The grade band descriptor, "Students describe the conclusions they made [or provide a rationale for their conclusions] based on the relationships they observed in the data" provides focus for a specific sensemaking goal in a given lesson.

Reflecting on previous PSETs' use of the SEP Tools, Amy noticed that her PSETs were writing a lot about the "hands-on" work that elementary students were physically *doing*, but underemphasizing the intellectual work that accompanied that material work (Ricketts, 2024). So, for this study she added a sensemaking "layer" to the SEP Tools, by asking the PSETs to explicitly attend to both the material and intellectual work of that sensemaking, using various prompts related to "figuring out" (described in detail next).

Data sources and methods of data collection

We generated data for this study over several weeks toward the end of the semester. Depending on the varying wishes of the PSETs and/or their cooperating teachers, the PSETs worked in pairs or individually to plan, teach, and reflect on a science lesson in their student teaching classroom. These activities included the most intensive, substantial assignments of the course, which required them to put into action (in their own teaching) the ideas they developed about sensemaking across the semester. The pedagogical goal of these activities was to focus the PSETs on student sensemaking from start to finish: as they prepared to teach the lesson, as they were teaching, and as they reflected on video of that teaching. From a research standpoint, these activities generated rich data sources that provided us with a view into the ways in which the PSETs were thinking about sensemaking, and about the ways that the SEPs serve as vehicles for that material and intellectual work. Table 2 provides a summary of the data sources analyzed in this study.

Preteaching planning data

Rather than teaching a lesson that they created "from scratch," the PSETs used lessons from the district's recently adopted science curriculum. This curriculum heavily emphasizes students' scientific sensemaking, and every unit is driven by an anchoring real-world phenomenon or design problem that students work to explain or solve all throughout the unit, using the SEPs as the vehicles for that sensemaking. The specific lessons were chosen from that curriculum by the PSETs' cooperating teachers, to fit in seamlessly with the flow of the classroom science instruction.

As part of their planning process, the PSETs analyzed the "Lesson Guide" from the existing curriculum, focusing on sensemaking. First, they identified one or more existing opportunities for student sensemaking, and the key SEP(s) that students would use to do that sensemaking work. Next, they used the corresponding SEP Tool to identify the focal

Table 2. Data sources.

Stage of study	Data Source	Description
Preteaching Planning	1) SEP Tool for Planning	PSETs highlighted (in color) the specific text of a SEP Tool that related to the sensemaking opportunities found in the existing Lesson Guide
	2) Curriculum Analysis	PSETs responded in writing to two prompts designed to help them analyze the student sensemaking opportunities found in the existing Lesson Guide
Postteaching Reflection	3) SEP Tool for Reflecting	PSETs highlighted (in color) the specific text of a SEP Tool that related to the student sensemaking they identified in the video of their lesson
	4) Sensemaking Reflection	PSETs responded in writing to three prompts designed to help them reflect on their students' sensemaking in the video of their lesson.

Table 3. Prompts used in the "Curriculum Analysis" and "sensemaking reflection" data.

Data Source	Prompt	Directions to PSETs	Focus
Curriculum Analysis (Pre teaching)	1) Specifically, what are the students doing when they use this practice?	Describe what the students will physically do when they are engaging in this practice. Your description should correspond to the highlighted text on the SEP Tool, and the sensemaking procedures in the Lesson Guide.	Material work
	2) What are the students trying to "figure out" when they use this practice?	Describe what students will be trying to "figure out" by using this practice. Your description should correspond to the highlighted text on the SEP Tool, and the sensemaking procedures in the Lesson Guide.	Intellectual work
Sensemaking Reflection (Postteaching)	1) What are the students trying to "figure out?"	Describe the unit-, chapter- or lesson-level phenomenon that the students are trying to explain in that lesson, contextualized within the lesson's driving question	Intellectual work
	2) What are they physically doing to figure that out?	Describe the students' observable behaviors—what can you see/hear them doing (physically)?	Material work
	3) How are they using a science practice to figure it out?	Use the language you highlighted in your completed SEP Tool, contextualized in the specifics of your lesson.	Intellectual work

component(s) of that practice that the students would use in the lesson. On the SEP Tool, they highlighted (in color) the specific text that related to the sensemaking in their lesson, in the K-2 or 3–5 grade band descriptors (data source 1). Later, they responded (in writing) to two Curriculum Analysis prompts (data source 2). Prompt 1 asked PSETs to attend to the material work of sensemaking, and Prompt 2 to the intellectual work (see Table 3).

Postteaching reflection data

After teaching, the PSETs reflected on the video of their lesson, again focusing on sensemaking. They identified the specific instance (s) in the video where they engaged their students in sensemaking, documenting the beginning and ending timestamps. They used the SEP Tools to identify the lesson's key SEP(s) and focal component(s) of that SEP, highlighting (in color) the applicable grade band descriptors (data source 3). They responded in writing to three prompts that were designed to support their attention to their students' sensemaking in the video (data source 4). The Sensemaking Reflection prompts, and the directions provided to the PSETs are found in Table 3. The yellow highlighting and red text in Table 3 came from the original directions that Amy provided to the PSETs, and are included here to contextualize our findings here. Various other data sources were collected, but they are not part of the analysis in this article. In future work, we expect to analyze the PSETs' lesson plans and the revisions they made to them after reflecting on these videos.

Data Analysis

To analyze these data, we used a hybrid approach (Fereday & Muir-Cochrane, 2006) of deductive ("top-down," literature-driven) and inductive ("bottom-up," data-driven) thematic analysis (Braun & Clarke, 2006) to understand what happened when the PSETs planned for and reflected on sensemaking in their own science teaching. We analyzed the data in three rounds. In each round, both authors independently wrote analytic memos and coded the data using NVivo software. Between rounds, we met to compare memos and

Table 4. Coding definitions.

Code	Definition
Material work	PSETs described students physically interacting with the material world, typically by manipulating physical or virtual materials and artifacts
Intellectual Work	PSETs described students' cognitive processes as they actively construct knowledge
Grain size: Macro	PSETs described the unit's anchoring phenomenon or the lesson's investigative phenomenon that K5 students are working to "figure out."
Grain size: Meso	PSETs described the specific kinds of sensemaking work that the various SEPs are used to doing
Grain size: Micro	PSETs described the metacognitive questions/decisions that K5 students must consider when using a particular SEP in the service of sensemaking.
SEP: Aligned	PSETs identified a SEP that is aligned with the particular sensemaking work students are doing
SEP: Misaligned	PSETs identified a SEP that is not aligned with the particular sensemaking work students are doing.

coding, redefine our codes as needed, and refine our analyses, coming to consensus on interpretations before moving to the next round.

In round one, we analyzed the data top-down, using the literature driven codes: "material work," and "intellectual work." Round one illuminated the degree to which the PSETs were able to articulate and distinguish between these two kinds of work involved in scientific sensemaking. Conversely, in rounds two and three, we analyzed the data "bottom-up" using codes we generated from the data itself. In round two, we documented in analytic memos that the PSETs described sensemaking at different sensemaking "grain sizes." We wondered if the PSETs' understanding of the ways that the SEPs are used for sensemaking at various grain sizes might be a useful dimension of their science practices-readiness (Bismack et al., 2022). Thus, in round two, we used the bottom-up codes "macro," "meso," and "micro," to account for these different kinds of sensemaking within our data. In round three, we documented in analytic memos that for some PSETs, the "key" SEP (s) that they identified in the (pre-teaching) planning data were different from the SEP(s) they identified in the (postteaching) reflection data. We then compared the key SEPs that all PSETs identified in the planning and reflection data to the explicit and/or inferred information provided in the curriculum. In this process, we recognized that the PSETs sometimes identified key SEPs that were not aligned with the particular sensemaking work of the lesson. Thus in round three, we used the bottom-up codes "aligned" or "misaligned." This round of analysis allowed us to better understand the ways that some PSETs' understanding of the SEPs changed across the data collection period. See Table 4 for our final codes and their definitions.

Findings

Our analyses generated three claims in response to our research question. When we asked them to explicitly attend to sensemaking as they planned for and reflected on their own science teaching:

(1) PSETs attended to both the material and intellectual work associated with sensemaking, but didn't always explicitly distinguish between the two.
(2) PSETs identified sensemaking occurring at multiple "grain sizes."

(3) Some PSETs improved, refined and/or deepened their understanding of how particular science and engineering practices are used for sensemaking as they shifted from the planning process to the reflecting process.

Claim 1: Articulating the material and intellectual work of sensemaking

Across the data set, the PSETs attended to both the material and intellectual work associated with sensemaking, but didn't always explicitly distinguish between the two. In the Curriculum Analysis data, the PSETs identified a total of 28 instances of sensemaking across all the lessons. In all 28 instances, PSETs were able to articulate both the material and intellectual work that their students would be doing as part of their sensemaking.

In 27 instances, the distinction between the material and intellectual work was not explicit. In these instances, the responses to Prompt 1 described the observable material work, but contextualized this material work as part of the intellectual work. In contrast, their Prompt 2 responses strictly focused on intellectual work, typically elaborating on the intellectual work they described in Prompt 1. (Note: The phrases in brackets were not part of the original data, we added these labels to facilitate the readers' understanding of our analysis.)

For example (see Table 5), in their Curriculum Analyses, PSETs H and I's responses to Prompt 1 ("What are the students doing when they use this practice?") include both material and intellectual work. "Students are looking at a reference book" represents material work, because it describes an observable activity in which students physically interact with ("looking at") a concrete artifact ("reference book"). The remainder of their Prompt 1 response demonstrates intellectual work, because it describes students' inferred

Table 5. PSETs' responses to prompts 1 and 2 in the curriculum analysis assignment.

PSETs	Prompt 1: What are the students doing when they use this practice?	Prompt 2: What are students trying to "figure out" when they use this practice?
H & I	Students are looking at a reference book [material work] to better understand the function of electrical devices [intellectual work].	Students are trying to figure out the input and output energies of various electrical devices [intellectual work].
R	Students traced their finger over the outline of multiple bar graphs of annual climate and precipitation of 3 locations (Creek, Blue, and Arc islands) [material work] to compare the average of both precipitation and climate. Students categorized the bar graphs into 2 categories, weak and strong [intellectual work].	Students are trying to figure out the similarities and differences of each climate/precipitation bar graph for all three islands (Blue, Arc, and Creek) [intellectual work]. Students also look for patterns in the bar graphs (i.e., Creek Island had a cold and dry winter this year, but does winter look like this every year on Creek Island?) [intellectual work].
J & K	Students will listen to a story about light as a class [material work]. As they hear the story, they will think about the evidence they found from the video to determine any connections about light that they see in the story [intellectual work].	Students are trying to figure out if it is possible to see in the dark. If it is not possible, they are trying to figure out what can be done to help us see in the dark [intellectual work].
S & T	Students are viewing a model of water in a pitcher being poured into three cups, representing three different appliances [material work].	Students are trying to figure out how to make the system work with the given energy amount (water must reach a certain threshold in order for the appliance to work). They will explain that either they need more water for all three cups to fill, [modify] the cups to where they need a lower threshold in order to work, or to take out a cup from the system [intellectual work].

Table 6. Sensemaking reflection: PSETs' "mixed" descriptions of material and intellectual work.

PSETs	Response to, "What are they physically doing to figure that out?"
U	Students are using writing utensils and/or art supplies to create drawings on their handouts [material work] that explain and support the responses that they generated to the statements given during the On-the-Fly Assessment [intellectual work].
N & O	Students are thinking to themselves about the properties of materials that they are holding [intellectual work]. They are feeling and looking at the materials through plastic bags [material work]. In groups of 4–6 students discuss and compare their observations with one another [intellectual work].
J & K	Students are thinking about ways to make a room dark [intellectual work], but because it is hard to get the classroom dark with the windows, projector, etc., the students will try to see in the dark in a different way by cupping their hands around their face while they look at the dice on their table [material work].

(or instructed) cognitive processes of knowledge construction ("to better understand"). In this case, they are constructing knowledge about "the function of electrical devices." In contrast, their response to Prompt 2 solely demonstrates intellectual work, as they refer to cognitive processes ("figuring out"), with no description of observable interactions with concrete materials. PSETs H and I's Prompt 2 response also elaborates on the intellectual work they described in Prompt 1, adding the details of "the input and output energies" as part of the "function" of the electrical devices. (The responses from PSETs R, J, and K, in Table 5 show a similar pattern).

In only one instance (see Table 5, PSET's S and T), the PSETs made appropriate and explicit distinctions between the material and intellectual work in their respective responses to Prompt 1 (material work) and Prompt 2 (intellectual work). In this instance, PSETs S and T's Prompt 1 responses strictly describes the students' observable material work (viewing a model of a system), while the Prompt 2 response describes the intellectual work they would engage in as part of the sensemaking process (explaining how to make the system work).

In the Sensemaking Reflection all PSETs were again able to articulate both the material and intellectual work of sensemaking. The same outcome emerged from these data that was found in the Curriculum Analysis data. That is, in one instance, the PSETs made appropriate and explicit distinctions between the material work (in their responses to Prompt 2) versus intellectual work (Prompts 1 and 3). But in the remaining instances, the PSETs still wrote "mixed" responses to Prompt 2. In comparison to the Curriculum Analysis data, these responses included more details about the observable behaviors and interactions with materials, but this material work was still contextualized as part of the intellectual work in their responses. Table 6 shows three examples of these "mixed" descriptions of material and intellectual work, which we identified in brackets. For Prompts 1 and 3, which asked about intellectual work, all PSETs' responses maintained an explicit focus on that intellectual work, just as they had in the Curriculum Analysis data.

Claim 2: identifying sensemaking at various "grain sizes"

Across the data set, the PSETs identified sensemaking occurring at various "grain sizes": macro-, meso- and microlevels (defined in Table 4). For example, the statements that PSETs A, B and C wrote in their Curriculum Analyses (see Table 7) demonstrate macro-level sensemaking, because they describe students "figuring" out their respective unit's anchoring phenomenon (a fossil stuck in a rock, seeds moving away from their tree of origin.) Their

Table 7. Macro, meso, microlevel sensemaking in the curriculum analysis.

PSETs	Prompt 2 Response	Grain size
A & B	"The students are trying to figure out how the fossil got stuck in the rock."	Macro
C	"The students are trying to figure out how seeds might move away from their tree of origin"	
D	"Students are shown a collection of data in line plot graph form and must decide that it is not an optimal way to look at a large collection of data, but rather to look at that data in bar graph form instead."	Meso
E	"The students are discussing] How is a map different from Earth? How is a globe similar to Earth? When is one more useful than another?"	
H & I	"[The students must consider] What have I learned about the electrical system and the function of electrical devices as energy converters?	Micro
F & G	"How the collected data/evidence explains how/why about the phenomena."	

descriptions of the sensemaking here do not get any more specific than "figuring out" a phenomenon.

In contrast, PSETs D and E's Curriculum Analysis responses "zoomed in" –beyond simply "figuring out" a phenomenon—on the specific kind of sensemaking work that students would be using a particular practice to do. Specifically, PSET D describes students making decisions about which kind of graph best represents their data, to help them compare the climates on multiple islands (Practice 4: Analyzing and Interpreting data; Component 1a: decide on an optimal display of data to represent phenomena). PSET E describes students comparing and evaluating features and limitations of two different kinds of models that both represent the Earth (maps and globes), which they will use to understand why we don't see stars (other than the sun) during the day (Practice 2: Developing and Using Models; Component 2: Identify limitations of models for explaining a phenomenon).

PSETs H and I, and F and G's responses demonstrate micro-level sensemaking, because they are zooming in to an even smaller grain size of sensemaking than the "meso" level, focusing on the metacognitive decisions students must make when engaging in the practices. For example, in their Curriculum Analysis, PSETs H and I identified Practice 8 (Obtaining, Evaluating, and Communicating Information), Component 4 ("students communicate scientific and/or technical information in written formats") as the main vehicle for sensemaking in the lesson. But instead of focusing on the mesolevel sensemaking work of communicating information in writing, they describe a metaconitive decision that would precede that writing—reflecting on "what have I learned" to decide what information they want to communicate "about the electrical system and the function of electrical devices as energy converters." Likewise, PSETs F and G drilled deep into the metacognitive decisions their students must make when choosing among multiple sources of data to use in an explanation. In these "micro" examples, the PSETs have zoomed in to an even smaller grain size of sensemaking than is represented in the text in the SEP Tools. Of the twenty-eight instances of sensemaking the PSETs described, eight were described solely at the macro-level, 18included both macro- and mesolevel sensemaking, and two included meso- and micro-evel sensemaking

In the post-teaching Sensemaking Reflection data, all PSETs described sensemaking in at least two grain sizes (see Table 8). As Amy intended, they described macro-level sensemaking (the lesson- or unit-level phenomenon or design problem) in response to Prompt 1, "What are the students trying to "figure out?" and meso-level sensemaking in response to Prompt 3, "How are they using a science practice to figure it out?" Eighteen of the PSETs

Table 8. Macro, meso, micro-level sensemaking in the sensemaking reflection.

PSETs	Responses to Reflection Prompts 1 and 3	Grain Size
N & O	Students are trying to figure out what is in the Mystery Mixture (based on their observations of the 4 materials). (Prompt 1)	Macro
	Students are using Practice 4: Analyzing and Interpreting Data. Students describe the conclusions they made [or provide rationale for their conclusions] based on the relationships they observed in the data (by identifying to the class why they chose the two materials that they did as being part of the Mystery Mixture (Prompt 3)	Meso
J & K	The students are trying to figure out how to make light in a dark theater. (Prompt 1)	Macro
	Students are using practice 8: Obtaining, Evaluating, and communicating information. They watch a video of a person walking through a dark cave with a flashlight and notice some ideas they see in the video. They discuss the ideas that they noticed ("I noticed the light get brighter as the guy got closer.") (Prompt 3)	Meso
E	The students are trying to answer the scientific question, "Why don't we see a lot of stars in the daytime?" using multiple models of the Earth (globes and maps) (Prompt 1)	Macro
	Students are using Practice 2: Developing and Using Models. They identify the limitations of the models of Earth (while the map is useful for many things, it's flat and therefore a different shape from the real Earth). They also provide a rationale for their conclusions (which model is better) from what they can observe from satellite pictures of the Earth. (Prompt 3)	Meso
U	The students are trying to figure out how to make drawings that communicate and explain their thinking about the questions: "Are the stars truly as tiny as they look?" and "Is the sun really bigger and brighter than the stars?" (Prompt 1)	Micro Macro
	Students are using Practice 2: Developing and Using Models. They developed models of where the Earth, the sun, and the stars are in space in relation to each other . . . . . . to make sense of the phenomenon of why stars that are bigger than the sun appear tiny (because they are light-years away) while the sun appears bigger and brighter (because it is the closest star to Earth). Some student responses went even further and identified limitations of models by adding comments such as "drawing not to scale" or "not actual size" when creating their models. (Prompt 3)	Meso Macro Meso

included the yellow highlighting in the original data, to identify text that came from the SEP Tools.

One participant (PSET U) described sensemaking at the macro, meso and micro grain sizes. He described macro-level sensemaking, explaining the lesson-level phenomenon (from Earth, the sun looks bigger and brighter than all the other stars) in his responses to both Prompts 1 and Prompt 3. His Prompt 3 response also described meso-level sensemaking, drilling down into the specific ways that the students developed models to explain that phenomenon, and how they identified limitations of those models. In addition, he described micro-level sensemaking in his response to Prompt 1 by describing a metacognitive question that students must reflect on as they developed their models. We consider this excerpt to be micro- (rather than meso-level) sensemaking because he is drilling down even deeper into the practice, by considering the *purpose* of this model—to communicate and explain one's scientific thinking to others, via drawings and captions. Notice here that his response to Prompt 3 included multiple samples of exact language from the SEP 2 Tool, which he highlighted in yellow.

Claim 3: describing how the science and engineering practices are used for sensemaking

Some of the PSETs improved, refined and/or deepened their understanding of how particular science and engineering practices are used for sensemaking as they shifted from the planning process to the reflecting process. When we closely compared the pre-teaching planning data (SEP Tool for Planning and Curriculum Analysis) to the curriculum Teacher Guides, we noticed a varied understanding amongst the PSETs in terms of which particular "key" practice is used for sensemaking in the lesson (and/or how that practice is used) as stated by the curriculum itself. Seventeen PSETs identified key SEPs that were aligned with the nature of the lesson's sensemaking work, four PSETs identified key SEPs that were misaligned with the sensemaking work, and two PSETs identified a combination of aligned and misaligned key SEPs. But in the post-teaching Reflection data (SEP Tool for Reflecting and Sensemaking Reflection), all PSETs identified a key SEP (s) that was aligned with the nature of the lesson's sensemaking, including those PSETs who identified misaligned SEPs in the planning data. In addition, one PSET identified (in his reflection data) additional key practices that were aligned with the lesson's sensemaking (that he had not identified in the planning data). See Table 9 for several illustration of these differences in the planning versus reflecting data, which we unpack below.

In the planning data, PSETs L and M identified a key practice that was misaligned with the nature of the lesson's sensemaking. In this lesson, first graders are viewing webcam photos of the sky, all taken simultaneously but in different parts of the world. The Lesson Guide from the curriculum explicitly identifies Analyzing and Interpreting Data (Practice 4) in the lesson objective, but PSETs L and M identified "Developing and Using Models" (Practice 2) as the lesson's key sensemaking practice (misaligned). Comparing the grade band descriptors that they highlighted on the SEP Tool ("students compare models … ") to their responses to the prompts ("looked through webcams … "), we think that the PSETs were (inappropriately) conceiving of the webcam photos as *models*, as opposed to the intended purpose of the photos (serving as *data*). However, in the reflection data, PSETs L and M identified SEP 4: Analyzing and Interpreting Data as the key practice, highlighting text from the SEP Tool: "describe patterns … in their observations (firsthand or from media)." Likewise, they describe the intellectual work of the lesson as "using their observations [the webcam photos] to determine the patterns throughout the six different places around the world that they observed," which is aligned with the nature of the sensemaking in the lesson. Thus, their reflection data represents a stronger understanding of the nature of the sensemaking work involved in modeling versus analyzing data.

Likewise, in the planning data PSETs (N & O) identified the key practice of their lesson as SEP 3: Planning and Carrying Out Investigations, which was not aligned with the nature of lesson's sensemaking. In this lesson, third grade students are attempting to identify which substances are present in a "Mystery Mixture," based on their observations of four substances in a previous activity. Comparing the grade band descriptors they highlighted to their responses to the prompts (see Table 9), we think that these PSETs conflated "predictions" with "interpretations." What they refer to as "prior knowledge (the previous activity where they became familiar with the 4 different substances)" is more appropriately conceived of as *data* that they previously collected. Thus, the sensemaking would be more aligned with analyzing and interpreting that data, as opposed to "predicting" an outcome. In the reflecting data, they instead identified SEP 4: Analyzing and Interpreting Data as the key practice, which is aligned with the nature of the lesson's sensemaking.

PSETs A & B also showed growth from the planning to reflecting stages. These PSETs planned and taught a fourth grade lesson about a fossil stuck in a rocky outcrop. In the planning data, these PSETs identified SEP 2: Developing and Using Models as the vehicle for the lesson's sensemaking. While these PSETs appropriately described the students'

Table 9. Planning versus reflecting data.

PSET(s)	Stage	Highlighted Text *Alignment*	Responses to prompts related to intellectual work
L & M	Planning	[SEP 2: Developing & using models] Students compare models to identify common features and differences. *Misaligned*	Students looked through webcams to different locations and defined the noticeable differences (day and night). Students are trying to figure out the different times of day from the six different locations.
	Reflecting	[SEP 4: Analyzing and Interpreting Data] Students describe patterns and/or relationships in the natural world in order to answer scientific questions using their observations (firsthand or from media) *Aligned*	Students are using SEP 4 to figure out what is similar between the places in daytime and nighttime. Students are using their observations to determine the patterns throughout the six different places around the world that they observed. They are using these patterns to determine whether the presented webcams are showing daytime or nighttime places.
N & O	Planning	[SEP 3: Planning & carrying out investigations] Students make relevant predictions: a) based on prior experiences b) specifying the outcome and reasons *Misaligned*	In groups, students will predict what the Mystery Mixture is, based on their prior knowledge [the previous activity where they became familiar with the 4 different substances]. They will give reasons for why they predict what they do. Students are trying to figure out what identifiable properties give them clues as to what two materials are in the "mystery mixture."
	Reflecting	[SEP 4: Analyzing and Interpreting Data] Students describe conclusions they made (or provide rationale for their conclusions) based on the relationships they observed in the data *Aligned*	Students describe the conclusions they made (or provide rationale for their conclusions) based on the relationships they observed in the data by identifying to the class why they chose the two materials that they did as being part of the Mystery Mixture. The Mystery Mixture was red with hard pieces in it, so they knew it was Material A (red powder—cinnamon) and Material B (small, hard white pieces—sea salt).
A & B	Planning	[SEP 2: Developing & using models] Students use models to: a) describe and/or predict phenomena, a) test cause and effect relationships or interactions concerning the functioning of a natural system. *Misaligned*	Students use the simulation tool to project differences in sea level. Students also use the simulation tool to navigate the changes of rocks and fossils over time. Students are trying to figure out how rocks and fossils change over time and why. They're trying to figure out how the fossil ended up in Desert Rocks National Park.
	Reflecting	(Instance of SEP 2 not included)	
U	Planning	[SEP 8] Students obtain and combine information from books, and/or other media from a credible source to explain phenomena. *Aligned*	Students make connections to information they obtained in previous lessons from other texts and media (i.e., personal observations from the Sim, data from page 19 of How Big is Big? How Far is Far?) Students figure out how today's text connects to readings and experiences from previous lessons.
	Reflecting	[SEP 8] Students compare and/or combine across complex texts and/or other reliable media to support engagement in other scientific and/or engineering practices *Aligned*	Students combine [ideas] across texts and other reliable media (such as the video *Lost in Light*) to support engagement in other scientific practices, particularly Practice 6, since they use information obtained from the *Handbook of Stars and Constellations* with data from other sources to construct explanations for why we cannot see the stars in the day and why light pollution affects visibility of the stars at night in urban areas.

material work of manipulating the simulation, they have inappropriately described this work in terms of using a model for scientific sensemaking. That is, in the Lesson Guide, the students are strictly "exploring" the simulation to better understand its functionality. The class discussion focuses narrowly on manipulating its features, including how to zoom in and out, and how to change the location, sea level, river speed and time. The students do not use the simulation for any kind of sensemaking. In the reflection data, these PSETs (wisely) did not refer to this activity at all, recognizing that the students were not using the simulation for sensemaking. (We note that in both the planning and reflecting data, these PSETs recognized two other sensemaking activities in the lesson, and identified SEPs that were aligned those activities' sensemaking work.)

In a final example, PSET U demonstrated growth across time in a different way. In his lesson, fifth grade students synthesize information from multiple nonfiction media sources about the distance from Earth to the Sun and other stars and their apparent brightness, to explain why the Sun looks bigger and brighter than all the other stars. In both the planning and reflecting planning data, a key practice he identified (SEP 8: Obtaining, Evaluating, and Communicating Information) is aligned with the ways students use the practice for sensemaking in the lesson. But in the Reflecting data, PSET U identified an additional key practice that was aligned with the lesson's sensemaking (that he had not identified in the planning data). That is, he again included SEP 8 (aligned), but also described that his students engaged in sensemaking by constructing explanations (SEP 6).

Discussion and implications

In this study, we set out to understand how we might better support PSETs' attention to the intellectual work of student sensemaking—in addition to the "hands on" material work that they typically espouse as valuable—as they planned for and reflected on their own science teaching. Our findings provide promising evidence that PSETs are capable of understanding that elementary science instruction can and should go beyond fun, hands-on science activities—it should also engage students in scientific sensemaking. By the end of the semester, every PSET was able to "put their finger on" one or more instances of sensemaking in their lessons and: 1) call out the material and intellectual work that their students did as they engaged in that sensemaking 2) describe sensemaking at multiple grain sizes and 3) describe how their students used a specific SEP for a particular kind of sensemaking. Below, we discuss some nuances of our findings, articulate the implications of our findings for practice, and situate our study in conversation with (and extending) the existing, related literature.

PSETs' attention to the intellectual work of the SEPs

Reflecting on our findings, we put forth that the focus on sensemaking supported PSET's understanding that engaging in the SEPs requires students to do both the material and intellectual work. Recall that a motivation for the design of this methods course was a previous experience in which Amy noticed the PSETs espousing a "touching and telling" approach to the SEPs (Ricketts, 2024), in which K12 students engage in the material, hands-on aspects of the SEPs (touching), while the teacher does most of the intellectual work (telling). For this study then, Amy consistently emphasized the sensemaking nature of the

SEPs, asking the PSETs to explicitly attend to both the material and intellectual work involved. Our data show that emphasizing the sensemaking nature of the SEPs provided the PSETs an opportunity to see beyond the material nature of the hands-on work: they were also able to articulate the intellectual work that the students would be doing/did. In contrast to the findings of Dalvi et al. (2021) and Arias and Davis (2017), our findings align with other research in which PSETs capably attended to the (student) intellectual work of the SEPs (Benedict-Chambers & Sherwood, 2024; Bismack et al., 2022). Furthermore, based on the findings from our study, the NextGen ASET SEP tool has been revised to include the question, "What sensemaking or intellectual work are students doing?" to accompany the original question, "What are the students doing?"

The embodied nature of sensemaking

In order to help the PSETs attend to both the material and intellectual work of sensemaking, Amy thought it would be helpful to ask the PSETs to write about these aspects of sensemaking separately. Thus, she asked the PSETs to respond to two prompts when using the SEP tools—one focused on material work, the other on intellectual work. Yet consistently across the data, the PSETs' responses to the question about material work almost always address both, with the material work contextualized as part of the intellectual work. With hindsight, we recognize that depending on the context of the lesson, it can be quite difficult to describe the material and intellectual work of sensemaking separately. Reflecting on the literature about embodied cognition (e.g., Wilson, 2002), we are reminded that these two kinds of work are deeply intertwined. Thus, when asking PSETs to consider these two dimensions as they attended to sensemaking, it may not be necessary (nor appropriate) to ask them to describe the material and intellectual work of sensemaking separately, as long as they attend to both.

Sensemaking occurs at various "grain sizes"

When informally reviewing the Curriculum Analysis data, Amy noticed that in response to the curriculum analysis Prompt 2, some PSETs (inappropriately) described the unit's driving phenomenon, when that particular lesson did not directly work toward explaining that phenomenon. Given that the science curriculum that the PSETs used persistently worked toward the goal of explaining the unit phenomenon, it is possible that these data reflected PSETs' attempts to associate the sensemaking work of one lesson in service of the overall sensemaking work of the unit (explaining the unit phenomenon). But it is also possible that these PSETs were over-attending to explaining the unit phenomenon, potentially at the expense of understanding the different ways that each practice engages students in a particular aspect of sensemaking. For example, constructing an explanation of the unit phenomenon requires a different kind of intellectual work than generating investigable questions about that phenomenon. Thus, in the Reflection data, prompts 1 and 3 were intended to focus the PSETs on the intellectual work of sensemaking at two different "grain sizes." Responding to these two prompts, PSETs could attend to the different ways that individual SEPs are used for sensemaking in the lesson (Prompt 3: Meso-level sensemaking), without losing their attention to the phenomenon the students are trying to "figure out" (Prompt 1: Macro-level sensemaking).

The construct of sensemaking grain size was something we had not considered (nor read in the literature) before analyzing these PSETs' work. Across the planning and reflecting data, some of our PSETs articulated an understanding of how a SEP is used for sensemaking at one grain size (typically, the "macro" size) more (or sooner) than other grain sizes, but they all described sensemaking at multiple grain sizes eventually. We hypothesize that attending to each grain size within a methods class may offer PSETs different "entry points" to understanding how the individual SEPs are used for a particular kind of sensemaking, which may help them to understand other grain sizes (and how to support student sensemaking at multiple grain sizes), as they become more experienced teachers. Thus, we propose that understanding how the SEPs can be used for sensemaking at various grain sizes may be another dimension of some PSETs' science practice-readiness (Bismack et al., 2022), thus extending the literature base around this construct. It might not be necessary to use these exact terms (grain size, macro/meso/micro) with PSETs to offer these multiple entry points. For example, Amy used everyday language (big, giant, medium, teeny tiny) and hand gestures to describe different scales of sensemaking, without ever uttering the words macro, meso, micro, or grain size.

Affordances of the SEP tools

We conjecture that asking the PSETs to closely attend to the language in the SEP Tools may have supported their understanding of how the individual science and engineering practices are used for sensemaking. We base this assertion on the changes (improvements) we saw in the reflection data (Claim 3), when Amy instructed the PSETs to use the language from the SEP Tools as they described the sensemaking work, as opposed to simply highlighting that language on the Tool itself (the instructions for the planning work). In accordance with Fick and Arias's (2020) theory of action that tools make implicit features of teaching explicit, we put forth that the language in the SEP Tools' grade band descriptors makes the specific sensemaking work more "visible" and accessible, by "breaking down the practice into obvious [components]" (p. 132). Thus, attending to that language (and using it in their teaching reflections) may have helped the PSETs to clarify the differences between the practices. The language of the SEP Tools may also support PSETs' understanding of the ways one practice can be used to support engagement in another practice. In our data, we see evidence for this conjecture in PSET U's reflection data (see Table A), where he uses (and highlights in yellow) the SEP 8 Tool phrase, "to support engagement in other scientific practices" as he describes how his students obtained and synthesized information across multiple texts and media (SEP 8) in the service of explaining (SEP 6) various light-related phenomena. In his planning data, he had not identified SEP 6 as part of the students' sensemaking work. Thus, the findings of our study provide evidence that the ASET SEP Tools (Alliance for Science Educators Toolkit, 2015) are useful in supporting PSETs' understanding of teaching science as facilitating sensemaking, when users attend closely to the text of the tool, and articulate both the material and intellectual work of the sensemaking.

Curriculum as a mediating factor

While we consider our findings to be promising, in terms of what PSETs can learn about teaching science as facilitating student sensemaking in teacher education programs, we also recognize the critical affordance of providing the PSETs with a curriculum that was already sensemaking heavy, which aligns with the findings of Forbes and Davis (2010). If the curriculum had not emphasized sensemaking, then the PSETs would likely need to add these opportunities into their lesson plans, which may or may not turn out to include actual sensemaking, as opposed to just hands-on “activities.” Given the variety of elementary science curricula in place in local school districts, we recognize that PSETs should have opportunities to engage with multiple curricula, of varying quality, so that they can recognize when a curriculum is lacking (or weak) in sensemaking opportunities, and have practice adapting these materials to create or enhance student sensemaking opportunities in their own lessons. In these endeavors, we think it wise to begin with a curriculum that includes ample sensemaking opportunities, to provide PSETs with “images of the possible” (Shulman, 1983, p. 495), before asking them to use the SEP tool to modify curriculum that has limited sensemaking opportunities. Interacting with curricula in these ways may help to develop what Brown (2008) refers to as “pedagogical design capacity,” where teachers understand whether and how to modify existing curricula to achieve a particular instructional goal. In a future article, we plan to investigate how a focus on sensemaking and the use of the SEP Tools supported these PSETs’ pedagogical design capacity, by analyzing the structured lesson plans they wrote after engaging with the curricular Lesson Guides, and the revisions they made to those plans after reflecting on the videos of their teaching.

Conclusions

This study addresses a continuing challenge in science education: the persistence of hands-on, “touching and telling” as the dominant vision of science instruction at the elementary level. Our findings shed light on the ways that a preservice course can be organized around opportunities for PSETs to consider the relationships between sensemaking and the Science and Engineering Practices (in our case facilitated by the ASET SEP Tools), and how those opportunities can be used to support an alternative conception of elementary science that goes beyond simplistic commitments to “hands-on.” Future research that follows PSETs into their own classrooms as beginning inservice teachers is needed to understand whether and how they: a) maintain a sensemaking approach in their science teaching, and b) use SEP Tools to support that approach. This research is especially critical in cases where the science curriculum does not center student sensemaking.

Ethical approval statement

California State University East Bay Institutional Review Board (CSUEB IRB) IRB #: CSUEB-IRB-2020–65

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Disclosure statement

Michele Korb holds the copyright for the ASET SEP Tools, which are found in Appendixes 1 and 2.

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APPENDIX 1: ASET SEP Tool: Analyzing & Interpreting Data, page 1

ASET Science & Engineering Practices (SEP) Tool: Analyzing & Interpreting Data

Name or ID:
Lesson/Unit Title:
Intended Grade:

Directions for use

Indicate if a component is present using Y (yes) or N (no) and then, if it is present, fill in the right 2 columns.
A single lesson will most likely not address each of the components below.
The numbering of these components is not meant to indicate they should be used in sequence, they are simply for reference.

SEP 4	**Analyzing and Interpreting Data:** Scientific investigations produce data that must be analyzed in order to derive meaning. Scientists use a range of tools-including tabulation, graphical interpretation, visualization, and statistical analysis- to identify sources of error in investigations and calculate the degree of certainty in the results. Engineering investigations include analysis of data collected in the tests of designs. This allows comparison of different solutions and determines how well each meets specific design criteria. Like scientists, engineers require a range of tools to identify patterns within data and interpret results.		
Components of SEP **In this lesson/unit plan, it is clear that *students* have a structured opportunity to:**	Present? **Y/N**	**What teacher actions were taken to facilitate this component for students?**	**What are the students doing?**
1) Clearly organize and display data to represent phenomena.			
2) Identify and describe relevant and meaningful patterns and relationships in data.			
3) Use statistical techniques to analyze data to address a scientific question or design solution			
4) Interpret data to provide evidence for, predict, and/or draw conclusions about phenomena.			
5) Analyze and interpret large data sets.*			
6) Identify and address variation and uncertainty in data sets.*			

* Not present until 6-8 Grade Band

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APPENDIX 2: ASET SEP Tool: Analyzing & Interpreting Data, page 2, K-2 and 3-5 grade bands

ASET Grade Band Criteria ***(Grade Bands: K-2, 3-5)***

Science & Engineering Practices		
SEP 4: Analyzing and Interpreting Data: Analyzing data in K-2 builds on prior experiences and progresses to collecting, recording, and sharing information. In 3-5 they build on K-2 experiences and progress to introducing quantitative approaches to collecting data and conducting multiple trials of qualitative observations.		
*By the end of the grade band **students** will have had a structured opportunity to develop an understanding of each of these. Individual lessons or units should include opportunities for **students** to practice one or more of the following components ......*		
	K-2 Grade Band	**3-5 Grade Band**
1) Clearly organize and display data to represent phenomena.	Students: a. record information (observations, thoughts and ideas) b. with guidance, organize (and sometimes share) given information (from data given or collected) using graphical or visual displays (e.g., pictures, pictographs, drawings, written observations, tables, charts)	Students organize data (e.g., from students' previous work, grade-appropriate existing datasets) using graphical displays (e.g., table, pictograph, chart, graph). This should include that they: a. decide on an optimal display b. label axes c. select appropriate intervals d. translate between representations (e.g. tables to graphs)
2) Identify and describe relevant and meaningful patterns and relationships in data.	Students describe patterns and/or relationships in the natural and designed world(s) in order to answer scientific questions and solve problems using their: a. observations (firsthand or from media) b. organization of the given information c. analysis of data from tests of an object or tool to determine if it works as intended This could include consideration of range (minimum and maximum), mode (what happens most often), comparisons (fewer than, greater than)	Students identify and describe patterns and/or relationships from the organized data. This could include consideration of: • Causation vs correlation • The role of the independent and dependent variable
3) Use statistical techniques to analyze data to address a scientific question or design solution	Not present until 3-5 Grade Band	Students analyze and interpret data to make sense of phenomena, using logical reasoning, mathematics, and/or computation
4) Interpret data to provide evidence for, predict, and/or draw conclusions about phenomena.	Students: a. compare predictions (based on prior experiences) to what occurred (observable events) b. describe the conclusions they made [or provide rationale for their conclusions] based on the relationships they observed in the data c. use their organized data to support or refute their ideas about why the design of a specific object or tool is best suited for the given intended purpose	Students a. use the organized data to find and describe relationships within the datasets b. describe how patterns provide evidence to support or refute a given conclusion about phenomenon c. use data to evaluate and refine design solutions d. make new predictions based on data (beyond the dataset)
5) Analyze and interpret large data sets.*	Not present until 6-8 Grade Band	Not present until 6-8 Grade Band
6) Identify and address variation and uncertainty in data sets.*	Not present until 6-8 Grade Band	Not present until 6-8 Grade Band

* Not present until 6-8 Grade Band

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