

## RESEARCH ARTICLE

# Elementary teachers' verbal supports of science and engineering practices in an NGSS-aligned science, engineering, and computational thinking unit

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## Abstract

Contemporary science education frameworks identify computational thinking as an essential science and engineering practice that supports scientific sense-making and engineering design. Despite national emphasis on teaching science, engineering, and computational thinking (NGSS Lead States, 2013), little research has investigated the ways that elementary teachers support students to engage in science and engineering practices (SEPs) within integrated science, engineering, and computational thinking curricula. This study explores how teachers provide verbal support of SEPs to upper elementary students during a 4-week NGSS-aligned curricular unit that challenged students to redesign their school to reduce water runoff. Students conducted hands-on investigations of water runoff and created computational models to test their designs. Teacher audio data during the classroom implementation was collected and qualitatively coded for different purposes of verbal support, such as to understand how (pragmatic), when, and why (epistemic) to use SEPs, in three focal lessons. Results show that teachers provided

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a range of pragmatic and epistemic supports for many different SEPs in science-focused and engineering-focused lessons, but support for a more limited variety of SEPs in the lesson focused on computational thinking. Across the lessons, the majority of teacher support aimed to help students engage pragmatically with the SEPs through sense making and engaging prior knowledge. In addition, teachers provided epistemic support more frequently in the science-focused lesson than in the engineering- or computational thinking-focused lessons. Results also demonstrate differences within the quality of the verbal support across lessons. This study provides insight into how teachers may differentially support SEPs in elementary classrooms and the kinds of learning experiences and educative materials teachers may need to provide equitable supports for students across SEPs.

**KEYWORDS**

interdisciplinary science, science education, teaching context

The Framework for K-12 Science Education (National Research Council [NRC], 2012) and the Next-Generation Science Standards (NGSS; NGSS Lead States, 2013) promote students' engagement in authentic science learning experiences. Teachers utilizing NGSS-aligned curricula are expected to integrate the disciplines of science, engineering, mathematics, and computer science through science and engineering practices (SEPs), disciplinary core ideas (DCIs), and crosscutting concepts (CCCs). These expectations are communicated through the integration of science and engineering within learning objectives, the inclusion of mathematics and computational thinking within the SEPs, and mathematical concepts included in the CCCs of scale, proportion, and quantity and patterns.

As more teachers strive to adapt to the NGSS and integrate engineering and computational thinking concepts and practices within science activities (Carr et al., 2012), curriculum materials are needed, particularly for elementary levels, that support these practices in alignment with NGSS (Carlson et al., 2014). However, curricular materials alone are not sufficient to ensure equitable learning opportunities across these practices. Science teachers may not have the same level of experience and disciplinary expertise with engineering and computational thinking, and elementary teachers may need support to integrate unfamiliar disciplines such as engineering design and computational thinking into elementary science classroom settings (Stohlmann et al., 2012). Thus, more research is needed to understand how to support elementary science teachers to engage students across engineering and computational disciplines SEPs (e.g., Crotty et al., 2017; Mehalik et al., 2008; Wendell & Rogers, 2013). In addition, when teachers are provided with curriculum materials, they may necessarily adapt materials to respond to students' in-the-moment ideas or specific classroom contexts (e.g., Remillard, 1999).

For example, teachers may need to provide in-the-moment support for students to engage in computational thinking practices if their students are having difficulty with computational activities as provided in curricular materials.

One of the ways that teachers adapt the curriculum materials is through the use of verbal supports to help students engage in learning (Barab & Luehmann, 2003; Songer et al., 2013). This can include supporting students to use academic language, sequence tasks, break down challenging tasks into manageable pieces, highlight key ideas, or make connections to students' everyday lives (Krajcik et al., 2000). For example, teachers can use verbal supports to change the complexity of the curricular task to make it accessible for specific students by giving examples of what responses may look like or by framing the response with sentence starters (Reiser & Tabak, 2014). In this way, verbal supports can help students engage in SEPs in ways that are authentic to that of scientists and engineers as called for by the NGSS (e.g., National Academy of Engineering and National Research Council 2014; NRC, 2012).

This study explores how elementary teachers verbally support fifth-grade students to engage in SEPs in an NGSS-aligned unit that integrates engineering design and computational thinking within science classrooms. Teachers were provided with a curricular unit focused on supporting students to address an engineering design challenge of reducing water runoff at their school. For the challenge, students designed solutions to authentic problems by investigating the world around them and developing computer models of the targeted phenomena to help them iteratively test and refine their solutions. The study focuses on how teachers helped students engage in a range of SEPs by providing pragmatic support (how to do a SEP) as well as epistemological support (when and why to do a SEP). We address the following research questions:

1. For what SEPs do elementary teachers provide verbal support, and to what extent are the supported SEPs aligned with the intended NGSS-aligned curriculum materials?
2. How do elementary teachers use pragmatic and epistemic verbal supports in whole-class discussions to support students' engagement with SEPs, and how do these supports vary across lessons that focus on different SEPs?

## 1 | BACKGROUND

### 1.1 | Engaging elementary science classrooms in the NGSS

As students participate in the learning communities of their classrooms, they construct knowledge by engaging in the practices of science, engineering design, and computational thinking (e.g., Lave & Wenger, 1991). Authentic opportunities for students to engage in these practices include learning experiences in which students define problems, engage in argument from evidence, and develop and use models (e.g., Bricker & Bell, 2008; Duschl & Osborne, 2002; Gobert & Buckley, 2000; Lehrer & Schauble, 2006; Windschitl et al., 2008). When students engage in these kinds of practice-based curricula, they have opportunities to learn the ways of thinking and reasoning inherent to science, engineering design, and computational thinking. For example, in BioKids, students collected data from their schoolyard to understand the biodiversity of species. After identifying and estimating the number of individual organisms, the students developed explanations about which areas of the schoolyard had the most biodiversity based on the number of different organisms and the abundance of those organisms (Songer, 2006). Such learning experiences that include SEPs in elementary school contexts can be particularly

important for students' identity development and potential interest in science, engineering, and computer science courses and careers (Morgan et al., 2016).

NGSS-aligned curriculum materials can specify SEPs of focus for students within certain lessons or units. However, teachers take these curricular materials, and with knowledge of their context and students, decide to implement them exactly as intended, adapt them to meet the needs of their students, or use them as a starting point to design other activities (Remillard, 1999). As such, teachers necessarily mediate the ways that students engage in the SEPs (McNeill, 2009). High-quality, NGSS-aligned curricular materials are then filtered through what the teacher chooses to implement and enact, which can be influenced by teachers' prior knowledge, skills, and beliefs (e.g., Ball et al., 2008; Gess-Newsome, 2015; Schoenfeld, 2016). Thus, despite SEPs being supported by the curricular materials, it is important to study both how teachers enact NGSS-aligned materials in science classrooms as well as how the teachers provide support for students to engage in the intended SEPs (Arias et al., 2016).

Considering this integration of practices across disciplines, more research is needed to understand how elementary teachers can support students to engage in intended SEPs that integrate engineering, mathematics, and computational thinking into science classrooms through NGSS-aligned instruction (e.g., Crotty et al., 2017; Wendell & Rogers, 2013). Research has examined how to support elementary students to engage in science and engineering (Watkins et al., 2018) and science and computation (Ketelhut et al., 2020). For example, Ketelhut and colleagues examined the ways in which elementary teachers integrated computational thinking into elementary science classes after a professional development experience and found positive effects on students' interest in computer science. However little, if any, research has investigated how elementary teachers can support students to engage in SEPs across science, engineering, and computational thinking disciplines as part of what scientists and engineers do to answer questions and design solutions. Thus, more research is needed that examines the ways that elementary teachers support students to engage in SEPs that integrate engineering design and computational thinking practices in science contexts.

## 1.2 | Pragmatic and epistemic verbal supports

One way that teachers can adapt the curriculum to help students engage in the SEPs is through the use of verbal supports. In particular, teachers can use verbal supports to engage students in a learning community (Moje et al., 2001) and differentiate classroom activities to fit the needs of their students. For example, teachers can use verbal supports to make content more accessible for students, help students to understand what a response may look like, use academic language, simplify difficult tasks into manageable parts, recognize key ideas, and connect content to their everyday lives (Krajcik et al., 2000).

In this study, we focus on *pragmatic* and *epistemic* verbal supports (e.g., Berland et al., 2016; McNeill & Krajcik, 2008) that occur when teachers are speaking (teacher talk). *Pragmatic* verbal support refers to instances in teacher talk that help students to engage in the SEPs through in-the-moment cues for how to do the practice. In this study, these supports include teachers verbally supporting students to make sense of new information (*sensemaking*) while engaging in a SEP, eliciting student ideas by engaging students' prior knowledge (*engaging prior knowledge*) with a SEP, or modeling engagement in a SEP by giving a demonstration or specific instructions (*doing*).

To support students in *sensemaking*, teachers can use *pragmatic* verbal supports to help students make sense of new information or build new understandings using the SEPs (e.g., Lehrer & Schauble, 2000; McNeill & Krajcik, 2008; Songer, 2006). For example, teachers can support students to use computational thinking in science contexts to understand how algorithms can represent scientific ideas (e.g., Hutchins et al., 2020) or support students to understand how computational models can help them test potential designs (e.g., Dasgupta et al., 2017). Through *sensemaking* support, teachers can then help students develop new understandings based on evidence and subsequently revise explanations and solutions to questions and problems of the natural world (Davis et al., 2019; Odden & Russ, 2019). However, supporting *sensemaking* through engagement with SEPs may be especially difficult for elementary teachers who may not have learned science in alignment with the NGSS, may often be required to teach multiple subjects, and may not have a background in science, engineering, or computational thinking (Davis et al., 2019). In addition, elementary teachers are often encouraged to focus on literacy and mathematics, resulting in little time for professional development in science (Smith & Craven, 2019).

Teachers may also use *pragmatic* verbal support to elicit relevant student ideas from the knowledge that their students already have by *engaging prior knowledge*. For example, within an NGSS-aligned unit, teachers can help students to reflect back upon specific science knowledge previously learned (e.g., Bransford et al., 1999), knowledge learned in other academic contexts (e.g., Shaughnessy, 2013), or knowledge gained through personal experiences outside of classroom learning environments (e.g., Linn & Eylon, 2011). In our study, teachers may also support students to *engage their prior knowledge* from within the curricular unit by asking students questions about the client's needs and the solution constraints or helping them to recall the project criteria.

In addition, teachers can use *pragmatic* verbal supports to support students in *doing* the targeted SEPs. For example, teachers can support students in engineering tasks in science contexts to define problems (e.g., Atman et al., 2007), create multiple potential designs (Luo, 2015), and use design tests to make informed revisions of their designs (Wendell & Banet, 2010).

*Epistemic* verbal support is teacher talk that supports students to understand the nature of specific disciplines and disciplinary thinking, including why they are using a particular practice and how that practice helps them answer the question, design a solution, or create a model (Ke & Schwarz, 2021; Lilly et al., 2020). For example, Kelly (2008) argues that it is important for students to build epistemic knowledge about producing, communicating, and evaluating knowledge as part of engaging in the discipline of science. In this study, for interdisciplinary classrooms, *disciplinary epistemic* verbal supports make explicit, in-the-moment connections to science, engineering, and computer science disciplinary professions (e.g., Berland et al., 2016; Lederman et al., 1998; Moore et al., 2014). *Classroom epistemic* supports help students understand the motivation and reasoning of their own science, engineering, and computer science learning activities within their own school contexts (e.g., Berland et al., 2016; Sandoval, 2004).

Helping students develop *disciplinary epistemologies* includes supporting students to learn about the nature of a discipline (i.e., what is the way of knowing in that discipline; e.g., Lazenby et al., 2020) and why SEPs are important in that field for ways of thinking about being a scientist, engineer, or computer scientist. This includes an awareness of what one needs to do as part of science, engineering, or computer science. For example, in science, *disciplinary epistemic* knowledge includes understanding the nature of science (e.g., Abd-El-Khalick & Lederman, 2000; Lederman, 1992), the ways that communities define the practices of their discipline (Kelly, 2008), and how scientific practices relate to the goals and the context of scientific

endeavors (McNeill & Krajcik, 2008). In engineering, *disciplinary epistemic* knowledge includes understanding the nature of engineering (e.g., Moore et al., 2014) and how engineering design practices relate to the purposes of engineering (ASEE, 2020). Likewise for computer science, *discipline epistemic* knowledge includes understanding the nature of computer science (e.g., K-12 Computer Science Framework, 2016) and how computational thinking practices relate to the goals and purposes of computer science.

For students, being able to explain how SEPs fit into their larger project, why they are engaging in SEPs, or the importance of SEPs in school contexts fits into a student's *classroom epistemology* (Berland et al., 2016; Sandoval et al., 2016). Supporting students to develop understandings with *classroom epistemic* support can help students to engage more meaningfully in SEPs through mastery goals for their classroom community rather than individualistic learning objective goals (e.g., Ames, 1992; Archer, 1994; Kelly, 2008). For example, teachers may focus on supporting students as a class to understand how and why to engage in argumentation from evidence rather than focusing on an individual student's ability to complete a worksheet. This shift in focus requires that students have an awareness of the purpose for the SEPs that they are engaging in and the ways that engaging in SEPs helps them to meet a larger project or course goal (Berland et al., 2016). For example, teachers may support students to understand how their investigation of the permeability of different surface materials will help them to redesign a surface that will better drain to fix a problem of water run-off. Having this understanding can help students to feel that they have greater autonomy in their learning (e.g., Herrenkohl & Guerra, 1998; Miller et al., 2018; Stroupe et al., 2019; Vedder-Weiss & Fortus, 2013) and increase their perceptions of activities as meaningful instead of believing that they are learning for the purpose of a standardized test or to please a teacher. This difference can help students shift from simply completing work for a grade to engaging in SEPs while building epistemic understandings (e.g., Jiménez-Aleixandre et al., 2000).

Prior research also shows that teachers' *epistemic* supports can affect the ways that students enact disciplinary epistemologies when engaging in SEPs within individual disciplines (e.g., Christodoulou & Osborne, 2014; González-Howard & McNeill, 2019). For example, teachers can provide in-the-moment *epistemic* support to help students understand how engaging in disciplinary practices relate to building knowledge in their classroom activities (Russ, 2018) or broader *epistemic* support to help students understand how engaging in disciplinary practices fit into the goals of a discipline (Gray & Rogan-Klyve, 2018). Furthermore, when, over time, teachers' *epistemic* supports are foregrounded and consistent across different contexts (Ke & Schwarz, 2021; Russ, 2018), then students may be able to build their own understanding of disciplinary epistemologies to guide the way in which they engage in disciplinary practices (Ruppert et al., 2019). For example, Ke and Schwarz (2021) examined how teachers' verbal support impacts upper elementary students' science epistemologies and students' engagement in the specific practice of modeling. Findings demonstrate that clear and consistent epistemic support that unpacks the practice impacts students' epistemologies about the science practice of modeling. Thus, teacher supports can impact students' abilities to build their epistemic knowledge and disciplinary understandings.

Furthermore, it is important for students to receive both *disciplinary* and *classroom epistemic* support so that they are able to situate the purposes of SEPs in a discipline as well as within their own classroom communities (Berland et al., 2016). For example, students can create computational models to test their engineering designs to solve a problem that is specific to a classroom science project while also being supported to understand how these practices relate to the ways that scientists and computer scientists similarly engage in modeling and testing designs to solve problems.

Taken together, investigating how teachers provide *pragmatic* and *epistemic* verbal support is particularly important as different SEPs have different types of embedded disciplinary knowledge, purposes, and processes—even towards similar goals. For example, asking questions for science and defining problems for engineering are listed together in one SEP yet represent very different epistemological goals for two separate disciplines (Cunningham & Kelly, 2017). In addition, teachers may verbally support some SEPs more or less than others or provide different levels of *pragmatic* or *epistemic* support across SEPs. For example, teachers may provide more *epistemic* support of science-focused SEPs but less *epistemic* support of computational thinking-focused SEPs due to their familiarity and understanding of the discipline. These differences in support may be necessary to situate SEPs to their classroom context or they may limit students' opportunities to engage in and understand the purposes of certain SEPs.

Research has examined the ways in which teachers support students' epistemic knowledge in the disciplines of science, engineering, and computer science (Lin & Chan, 2018; Tan et al., 2019). However, there has been less consideration of teachers' *epistemic* supports in interdisciplinary contexts. In interdisciplinary contexts, *epistemic* supports are important to consider as they can offer students opportunities to build richer understandings of each integrated discipline (e.g., Tytler et al., 2021) and the ways in which the disciplines support each other and work in tandem. Thus, research needs to illustrate how teachers use both *pragmatic* and *epistemic* supports to help students understand and engage in SEPs that span multiple disciplinary contexts, particularly in elementary classroom settings.

Furthermore, teachers' choices in how and when to use both types of verbal supports when implementing a curricula may help students to have power in building their own classroom epistemologies as well as connecting these personal epistemologies to the epistemologies of disciplines. Examining teachers' *pragmatic* and *epistemic* verbal supports is then important due to the impact they may have on students' epistemic agency (i.e., agency to shape knowledge production and practices; Miller et al., 2018; Stroup, 2019). For example, Ko and Krist (2019) suggest that teachers can strategically implement NGSS-aligned projects, specifically, to help students develop epistemic agency. The ability of teachers to do so may be important as the NGSS goal of students learning science-as-practice may require students to become epistemic agents, involved in the shaping the knowledge and practice of a science community (Stroupe, 2019). Teachers' use of *pragmatic* supports, focused on helping students to engage in science practices to help students build knowledge as a community of learners, may then help students to become epistemic agents; teachers' use of *epistemic* supports, focused on making connections to disciplines, may help students to understand how their classroom community is enacting disciplinary practices. Although this study does not focus on students as epistemic agents, understanding teachers' use of verbal *pragmatic* and *epistemic* supports may be an important step towards increasing students' power in interdisciplinary learning through their epistemic agency.

In the context of elementary classrooms, we propose that teachers can help students to develop epistemic agency by engaging students in decision-making about use of the SEPs for answering questions and solving problems. Part of this sensemaking process involves engaging with the productive uncertainty of those decisions (Manz & Suárez, 2018), particularly in the context of engineering where the best answer is often unclear and needs to be distinguished by prioritization. Being able to do this work requires that students understand how and why to engage with the SEPs and how it will support their sensemaking process. That epistemic support could focus on both understandings how the processes that the students are engaged in are part of the practice of professionals (*discipline epistemic*) and also understanding how the practices will help to solve the problems of the classroom (*classroom epistemic*). The *pragmatic*

*support* could take the form of information for the students about how to use the practices for sensemaking in science and engineering. Our study characterizes the verbal supports that teachers provide to support students' engagement in the SEPs in an interdisciplinary context.

In this study, we consider the ways that elementary teachers provide verbal supports of SEPs during the implementation of an interdisciplinary, NGSS-aligned curricular unit in a fifth-grade class. Particularly, this study focuses on the kinds of verbal supports teachers use during an NGSS-based project and examines any differences in pragmatic and epistemic support across lessons focused on different SEPs. The results of this study may contribute to understanding the different ways that teachers implement NGSS-aligned curricula to help their students engage with different disciplinary practices (Barab & Luehmann, 2003).

## 2 | METHODS

This study uses an embedded, single case study methodology (Yin, 2018) to examine fifth-grade teachers' verbal supports as they co-teach an interdisciplinary, NGSS-aligned project across three disciplinary-focused lessons within a single classroom setting. As our research questions ask "how and why," do not require control over the teachers' behavior, and focus on events occurring in the moment, we chose to utilize a case study method (Yin, 2018, p. 9). We define the case as two teachers with science backgrounds who implemented the project in their co-taught classroom. Furthermore, an embedded, single case study is appropriate for this study because our research questions aim to describe and understand what happened in a single, bounded context (Miles et al., 2020), and we believe that our data represents an unusual case in implementing an interdisciplinary, NGSS-aligned project (Yin, 2018). Specifically, these teachers have atypical content knowledge for elementary teachers, were co-developers of the curriculum, and had access to knowledge of the curricular goals and educative supports. We examined teachers' verbal supports during whole-class discussion throughout the implementation of the NGSS-aligned project to examine similarities and differences between the implementation of the three disciplinary-focused lessons with the analytical frame of teachers' pragmatic and epistemic verbal supports.

### 2.1 | Setting and participants

The study took place in a public elementary school located in the southeastern United States. Two fifth-grade teachers, given the pseudonyms Ms. Banet and Mr. Skelton, co-taught an NGSS-aligned, 4-week project curriculum with a class of 27 students. The students in this class reflected the school demographics, which were 38% Black, 13% Hispanic, 38% White, 6% Asian, and 5% Multiple Races; 18% had disabilities, 17% were Emerging Bilinguals, and 53% qualified for free or reduced-price lunch. Both of the teachers hold an undergraduate degree in a field of science and have over 5 years of teaching experience. Ms. Banet is a classroom mathematics and science teacher, and Mr. Skelton is the school's science, technology, engineering, and mathematics (STEM) coordinator whose role included pushing into classrooms to implement project-based activities. Both Ms. Banet and Mr. Skelton had worked together on a pilot version of this project the previous year and served as co-designers of the curricular unit used in this study. Both teachers received 1 week of professional development about the NGSS, engineering, and computation, as well as monthly meetings leading up to the implementation. Teachers did

not have explicit professional development on verbal supports, but as part of the professional development meetings gave feedback on educative materials, including places where verbal supports could fit within the project. This state had not adopted NGSS, so teachers and students had little prior experience with some of the SEPs.

2.2 | Curricular unit

The overall goal of the curricular unit was for students to use science, engineering design, and computational thinking to redesign the grounds of their school to reduce water runoff while considering design criteria such as requirements for a parking area, grassy fields, and play areas (Chiu et al., 2019). This study focuses on three of the 13 lessons within the larger curricular unit. We selected these lessons because of their focus on a diverse set of SEPs, with one lesson focusing on planning and carrying out investigations and constructing explanations (science-focused lesson), another lesson focused on obtaining, evaluating, and communicating information and designing solutions (engineering-focused lesson), and the third lesson focused on using mathematical and computational thinking and developing and using computational models (computational thinking-focused lesson). These lessons are summarized in Table 1. For each lesson, we noted the intended, focal SEPs from the Teachers' Guide. These focal practices were specifically named by the Teachers' Guide at the front of each lesson so that they were clearly available to the teachers.

TABLE 1 Summary of selected NGSS-aligned lessons

| Lesson name                           | Focal SEPs                                                                                                                                                  | Learning objectives addressed in the curriculum                                                                                                                                                                                                                                                                                                                                                                                                    |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Science-focused lesson                | (a) Planning and carrying out investigations<br>(b) Analyzing and interpreting data<br>(c) Constructing Explanations and engaging in argument from evidence | (a) <i>Carry out investigations</i> and (b) <i>analyze data</i> to show how water absorption relates to surface materials and amount of rainfall. (c) <i>Construct explanations</i> by creating a claim using evidence based on their investigations and analysis ( <i>engaging in argument from evidence</i> ) to describe how water absorption and runoff relates to surface materials and amount of rainfall (claim, evidence, reasoning; CER). |
| Engineering-focused Lesson            | (a) Obtaining, evaluating, and communicating information<br>(b) Designing solutions                                                                         | (a) <i>Generate multiple design solutions</i> limiting the amount of water runoff that flows downhill impacting other areas and compare those solutions to determine which solution best meets the criteria of the design challenge. (b) <i>Communicate information</i> about the design process and tests used to develop their engineering design solution to reduce runoff from the schoolyard.                                                 |
| Computational thinking-focused lesson | (a) Using mathematics and computational thinking<br>(b) Developing and using computational models                                                           | (a) Understand <i>developing computational modeling</i> as part of science and engineering. (b) <i>Interpret and test computational models</i> that calculate total rainfall and total water absorbed involving variables, loops, expressions, and change and set commands.                                                                                                                                                                        |

Abbreviations: NGSS, Next-Generation Science Standards; SEP, science and engineering practices.

The learning objectives addressed in the curriculum for the science-focused lesson were that students (a) *carry out investigations* and (b) *analyze data* to show how water absorption relates to surface materials and amount of rainfall as well as (c) *construct explanations* by creating a claim that answers a question and using data as evidence (*engaging in argument from evidence*) to describe how the evidence supports the claim (claim, evidence, reasoning; CER; Berland & Reiser, 2009). Due to the curriculum's focus on CER and the nature of the CER framework, which is an argumentation framework, we did not distinguish between instances of *constructing explanations* and *engaging in argument from evidence* (e.g., Berland & Reiser, 2009). Instead, we adopted the unified perspective described by Berland and Reiser (2009) and discussed them as a single construct in our analysis. This was appropriate in our study because the curricular unit took a unified approach to these two SEPs, closely intertwining them with CER, such that the claims students made were causal or mechanistic explanations supported by evidence and reasoning. Activities that targeted the learning objectives in the science-focused lesson were carried out over the course of six class periods towards the beginning of the project curriculum.

The stated learning objectives for the engineering-focused lesson were that students (a) *generate multiple design solutions* that limit the amount of water runoff that flows downhill and impacts other areas and compare those solutions to determine which solution best meets the criteria of the design challenge and (b) *communicate information* about the design process and tests used to develop their engineering design solution to reduce runoff from the schoolyard. Activities targeting these learning objectives were implemented over three class periods in the middle of the project.

The stated learning objectives for the computational thinking-focused lesson were that students (a) *develop computational models* as part of science and engineering and (b) *interpret and test computational models* that calculate total rainfall and total water absorbed involving variables, loops, expressions, and change and set commands. Activities targeting these learning objectives were carried out over the course of three class periods towards the end of the project.

## 2.3 | Data sources and analysis

Data sources included transcriptions of audio data extracted from video that captured whole-class discussions across the three lessons over the course of 12 class periods and the Teachers' Guide. Each class period was approximately 50 min in length, so an approximate total of 10 h of data were collected across the lessons. In the video, only whole-class discussion was clearly audible, so the transcript of audio data was limited to whole-class discussion. The following approximate length of audio data of whole-class discussion was analyzed for each lesson: science-focused lesson: 170 min; engineering-focused lesson: 100 min; computational thinking-focused lesson: 130 min. Thus, group or individual work times in which the teacher was not leading whole-class discussion were not transcribed. The Teacher's Guide was used to determine the focal SEPs for each lesson.

### 2.3.1 | Identifying supported SEPs

To examine which SEPs teachers were supporting through teacher talk in whole-class discussions as they implemented the curriculum, two researchers read each transcript together sentence by sentence. As the researchers read the transcript, they identified a specific SEP being supported using the definitions from the Framework for K-12 Science Education (National

Research Council, 2012). The researchers labeled a portion of the transcript with the SEP until it was clear that a different SEP was being supported, in which case the next portion of the transcript was labeled with the new SEP. For example, we identified the different SEPs supported in a portion of whole-class discussion led by Mr. Skelton in Table 2.

Thus, the supported SEPs were identified and labeled across portions of the whole-class discussion, rather than by the changes in who was speaking (turn of talk). This decision was made because such support was generated across multiple turns of talk or multiple SEPs could be supported within a single turn of talk. We did not identify any instances where multiple SEPs were supported concurrently in the transcript. Thus, each portion of the transcript was labeled with a single, implemented SEP. The intended SEPs from the Teacher's Guide and implemented SEPs from the transcripts were then compared.

2.3.2 | Teacher talk codes

To examine how teachers supported students to engage in the SEPs through teacher talk in whole-class discussions, each teacher turn of talk was coded. As turn of talk refers to a group of sentences with a single speaker, a new turn of talk began when another person spoke or when there was a lengthy pause noted in the transcript. The purpose of the teachers' words built throughout a turn of talk, rather than through each single sentence, which is why we chose to code by turn of talk instead of at the sentence or utterance level. Each turn of talk could be coded with one or multiple codes. Because turns of talk could be double coded and varied in length, we report findings in terms of percentages of the discussion rather than counts of codes applied to turns of talk.

For this analysis, three researchers all coded the same 5% of the data, then discussed disagreements and refined the codebook to use for the next 5%. This process was repeated four times until the percent agreement was greater than 85% for 20% of the data (Miles et al., 2020, p. 79). Two researchers then coded the remaining data using the final version of the codebook and discussed any uncertainties in their codes. This coding was used previously to examine the specific activities

TABLE 2 Example of identifying the SEPs supported

| Mr. Vista's verbal support in the science-focused lesson                                                                                                                                                                                                                                                                                                                                              | SEP supported                                |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
| So the way that they get that decimal point is they add up all the numbers from each game and then they divide by the number of games.<br>That's essentially what we did here because you guys all took data from different experiments.<br>So we tried to find the center point.<br>And what we found was the concrete left 13 sixteenths of an inch of water on top and only absorbed 3 sixteenths. | Using mathematics and computational thinking |
| And then we looked at the grass.<br>This is everybody's data.<br>The grass only left 7 twentieths on top and absorbed 13 twentieths.<br>Now I know sixteenths and twentieths are not the same but they are close.<br>So it does tell us still that the grass absorbed a lot more than the concrete.                                                                                                   | Analyzing and interpreting data              |

Abbreviation: SEP, science and engineering practices.

within only the engineering-focused lesson (Lilly et al., 2020), and this study expands upon this pilot study to explore the differences across the science-, engineering-, and computational thinking-focused lessons. Thus, we used a provisional coding approach, which began with an a priori list of codes based on previous studies and the framework (Miles et al., 2020, p. 69).

There were four levels of codes, each level becoming more specific (Figure 1). First, each turn of talk in which a teacher spoke (teacher talk) was coded for whether it was focused on *supporting curricular engagement* or *classroom management*. If a turn of teacher talk included instances of both *supporting curricular engagement* and *classroom management*, then, it was coded as *supporting curricular engagement* to make sure to capture any possible instances of support. Teacher talk coded as *supporting curricular engagement* included any verbal changes to the activity or clarification of concepts that supported students to engage with the curricular material while turns of talk that included only going over logistics, behavioral management, or calling on students in large group discussion were coded as *classroom management*. Turns of talk coded as *classroom management* were not coded with any further specificity because they did not contain instances of SEP support.

In the second level of coding, turns of talk that had been coded as *supporting curricular engagement* were examined for their support of students' engagement with a specific SEP. If a turn of talk supported students by narrowing a broad question or extending the group conversation (e.g., "does anyone have something to add?") but were not clearly supporting a specific SEP, they were coded as *not SEP-specific*. These turns of talk were not coded with any additional specificity because the research questions focus on verbal support of SEPs. In contrast, when a specific SEP was being supported in a turn of talk, it was coded as *SEP-specific* and additional Level Three and Level Four codes were applied to consider the purpose of the verbal support (i.e., *pragmatic* and *epistemic*).

Every turn of talk that was coded as *SEP-specific* was coded with Level Three codes. Turns of talk that supported students to engage in the SEPs were coded as *pragmatic*, *epistemic*, or both. The *pragmatic* code applied when teachers verbally supported students to make sense of the SEPs or explained how to engage in the SEP, and the *epistemic* code applied when teachers verbally supported students to connect an immediate activity to a broader purpose. A turn of talk was coded as both *pragmatic* and *epistemic* if it contained examples of both types of support. This double

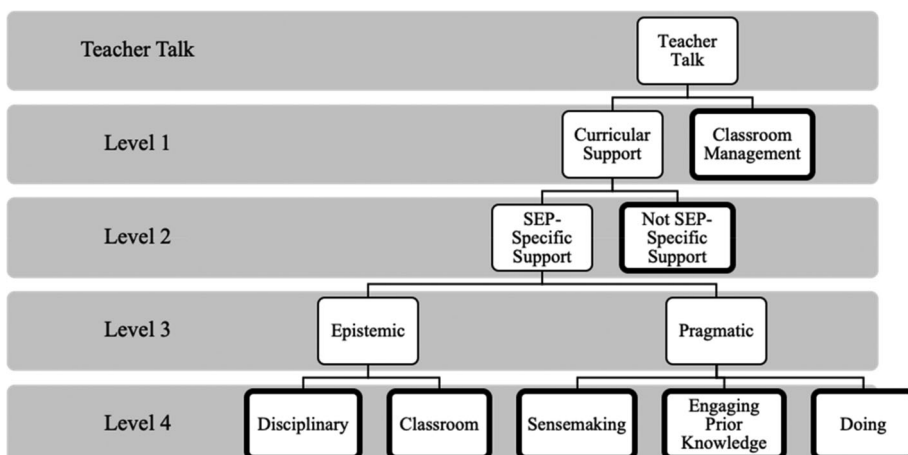


FIGURE 1 Coding hierarchy

coding of *pragmatic* and *epistemic* was performed to capture all instances of both purposes of support so that these turns of teacher talk could be more closely examined by Level Four codes.

In the fourth level of coding, *pragmatic* turns of talk were further coded as those that supported students to make sense of new information or build new understandings, *sensemaking*, elicited relevant student ideas from the knowledge that the student already has, *engaging prior knowledge*, and modeled how to do a particular practice, generally in the form of instruction or demonstration, *doing*. These coding choices were inductive, based on emerging trends of *pragmatic* verbal support. *Epistemic* turns of talk were further divided into those that supported students to see how a practice fit into the larger project, coded as *classroom*, and those that supported students to see how a practice fit within the larger discipline, coded as *disciplinary* (Berland et al., 2016). Each turn of talk could be coded as any combination of these fourth-level codes if examples were present. Examples of these codes, as well as the other most specific codes (bolded, Figure 1), are shown in Table 3. After coding for each of these categories, the transcripts were analyzed for emergent themes and patterns in the applied codes. Researchers looked across turns of talks for patterns of these emergent themes and discussed these patterns along with disconfirming evidence as reported in the findings section below.

### 3 | FINDINGS

#### 3.1 | RQ1: What SEPs do teachers support in whole-class discussions and to what extent are the supported SEPs aligned with the intended NGSS-aligned curriculum?

##### 3.1.1 | Identifying supported SEPs

The amount of verbal support of SEPs varied across the lessons (Table 4) as teachers sometimes chose to add support of additional SEPs to help students engage in the curricular activities. In the science-focused lesson and engineering-focused lesson, teachers drew upon one or more additional SEPs beyond those specified as the focal SEPs to support their students. For example, the focal SEPs outlined by the Teachers' guide for the science-focused lesson were planning and carrying out investigations (21%), constructing explanations and engaging in argument from evidence (45%), and analyzing and interpreting data (14%; Table 4). But when implementing the science-focused lesson, teachers also supported multiple SEPs beyond these focal SEPs, including defining problems (4%), developing and using models (6%), and using mathematics and computational thinking (10%). An example of adding mathematics and computational thinking support in the science-focused lesson occurred when analyzing data from their experiment that tested surface materials towards designing a playground with less runoff. To help support students in analyzing the data, Mr. Skelton also provided support to help students to understand how and why they had used a specific mathematics concept when calculating the data, asking:

Do you see anything that is curious to you, that is interesting to you, anything that sticks out to you at all? You'll notice that it calculated averages on the bottom. Why do we calculate an average for something? Does anybody remember from your math classes? I know some of you have done, or, let me put it this way, why do you find the mean of something? That's another way of saying the average. Why do we find that?

TABLE 3 Example codes

| Codes                    | Definition                                                                                          | Examples                                                                                                                                                                                                                                                                        |
|--------------------------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Epistemic                |                                                                                                     |                                                                                                                                                                                                                                                                                 |
| Disciplinary             | Explicitly explains how practices fit within the larger discipline                                  | <i>This is really what engineers do, is they form science experiments first and then they figure out how to design a solution in many cases.</i> —Mr. Skelton, engineering-focused lesson                                                                                       |
| Classroom                | Explicitly explains how an activity fits into the larger project or orients students to the project | <i>If you recall from yesterday, we were trying to figure out how we were going to make our computer model reflect or conclude the things that we knew based on our experiments, the hands-on experiments that we did.</i> —Mr. Skelton, Computational Thinking-Focused Lesson  |
| Pragmatic                |                                                                                                     |                                                                                                                                                                                                                                                                                 |
| Sensemaking              | Supports students to make sense of new information or build new understandings                      | <i>So did the water actually pass through the soil? What do you guys think?</i> -Ms. Banet, Science-Focused Lesson                                                                                                                                                              |
| Engaging prior knowledge | Supports students to draw upon information they had already been learned                            | <i>Let's remind ourselves really quickly, what was [Principal]'s challenge to us.</i> —Mr. Skelton, engineering-focused lesson                                                                                                                                                  |
| Doing                    | Models how to do a particular practice, generally in the form of instructions or a demonstration    | <i>So you're taking your claim and your evidence and you're combining them to create your reasoning.</i> —Ms. Banet, Science-Focused Lesson                                                                                                                                     |
| Not SEP-specific         | Supports students but not towards a specific SEP                                                    | <i>What's another reason? What else?</i> —Mr. Skelton, Science-Focused Lesson                                                                                                                                                                                                   |
| Classroom management     | Focuses on facilitating movement in the classroom, calling on students, or managing behavior        | <i>10 seconds to be in your seats. Thank you. 9, 8, 7, 6, 5, 4, 3, 2, and 1. Back table is with me, excellent. Thank you. The front table, I'm still waiting. The middle table on the right-hand side there, thank you.</i> —Mr. Skelton, Computational Thinking-Focused Lesson |

Abbreviation: SEP, science and engineering practices.

Thus, to support the focal SEPs outlined by the Teachers' Guide, the teachers drew upon a variety of additional SEPs that were not suggested by the Teachers' Guide.

In the engineering-focused lesson, the majority of teacher talk that was SEP-specific supported students towards defining problems (52%), which was not a focal SEP for that lesson (Table 4). The focal SEPs of designing solutions (17%) and obtaining, evaluating, and communicating information (22%) were supported less than half as much as defining problems. For example, at the start of an activity in the engineering-focused lesson, Mr. Skelton led the class in a detailed discussion about each of the design constraints to help the students remember the problem definition before they started working on their designs. This discussion began with discussing the budget constraint:

TABLE 4 Percentage of support for SEPs across NGSS-aligned lessons

| Science and engineering practices                              | Science-focused lesson | Engineering-focused lesson | Computational thinking-focused lesson |
|----------------------------------------------------------------|------------------------|----------------------------|---------------------------------------|
| Defining problems                                              | 4%                     | 52%                        | —                                     |
| Developing and using models                                    | 6%                     | 9%                         | 46%                                   |
| Planning and carrying out investigations                       | 21%                    | —                          | —                                     |
| Analyzing and interpreting data                                | 14%                    | —                          | 4%                                    |
| Using mathematics and computational thinking                   | 10%                    | —                          | 50%                                   |
| Constructing explanations & engaging in argument from evidence | 45%                    | —                          | —                                     |
| Designing solutions                                            | —                      | 17%                        | —                                     |
| Obtaining, evaluating, and communicating information           | —                      | 22%                        | —                                     |

*Note:* Bolded percentages are the lesson's focal SEPs as suggested in the Teachers' Guide; columns add vertically to 100% of the teacher talk that is coded as supporting for each lesson.  
Abbreviations: NGSS, Next-Generation Science Standards; SEP, science and engineering practices.

Mr. Skelton: Let's remind ourselves really quickly, what was [Principal]'s challenge to us? What did he want us to do?  
Student: Don't go over the budget.  
Mr. Skelton: Don't go over the budget. So let's talk about what that means really quickly because I understood that there was a lot of conversation about what does that mean. What is your budget?

A similar discussion about constraints occurred at the start of each activity in the engineering-focused lesson, leading to 52% of teachers' verbal support in whole-class discussion focused on problem definition. For example, another activity in the engineering-focused lesson began with discussing the surface material constraints:

Female teacher: You're making your first design in your notebook. Now, keep in mind, how many squares are allotted for buildings, parking lot, the field, and the play area. You can't change those, right? ... So, how many spaces did you guys say for buildings?  
Male Teacher: five  
Female Teacher: parking lot?  
Student: four  
Female Teacher: grassy field?  
Student: five  
Another student: I thought there were six grassy fields.  
Male Teacher: no, remember we re-voted on that one.  
Student: oh, yeah...  
Male Teacher: and then the play area is two  
Female Teacher: So, there you go. So keep in mind that these areas can have different types of surfaces.

Thus, while the focal SEPs were supported throughout the science-focused and engineering-focused lessons, they did not always receive the largest percentage of verbal support.

In the computational thinking-focused lesson, using mathematics and computational thinking (50%) and developing and using models (46%) made up nearly the entirety of the support offered. Thus, teachers' verbal support within the computational thinking-focused lesson was in greater alignment with the focal SEPs described by the curricular materials.

### 3.1.2 | Not SEP-specific support

Teachers also chose to add verbal support that was not SEP-specific. The Science-Focused Lesson had less not SEP-specific support (10%) than the engineering-focused (29%) or computational thinking-focused (22%) lessons. Specifically, the new ways of using technology in the engineering-focused and computational thinking-focused lessons may have led to more not SEP-specific support in the form of helping students access the technologies. For example, in the engineering-focused lesson, Ms. Banet supported students to save their work, "Control S, there you go." Similarly, in a computational thinking-focused lesson, Mr. Skelton said "Go to Google Classroom and click on the link." Ms. Banet said, shortly afterwards, "Alright, click on assignments and it should come up now!" There were many examples of this type of not SEP-specific support for simply navigating the computational modeling program in both the engineering-focused and computational thinking-focused lessons.

## 3.2 | RQ2: How do elementary teachers use pragmatic and epistemic verbal supports in whole-class discussions to support students' engagement with SEPs, and how do these supports vary across lessons that focus on different SEPs?

Table 5 shows the percentages of pragmatic and epistemic support across the three disciplinary-focused lessons.

### 3.2.1 | Pragmatic support

Most of the SEP-specific support across all the lessons was pragmatic (Table 5). In terms of the *pragmatic* support, both the science- (54%) and computational thinking-focused (59%) lessons

**TABLE 5** Purposes of SEP-specific support across NGSS-aligned lessons

| Type of verbal support | Science-focused lesson ( <i>n</i> = 179) | Engineering-focused lesson ( <i>n</i> = 66) | Computational thinking-focused lesson ( <i>n</i> = 341) |
|------------------------|------------------------------------------|---------------------------------------------|---------------------------------------------------------|
| Pragmatic              | 79%                                      | 67%                                         | 74%                                                     |
| Epistemic              | 11%                                      | 5%                                          | 4%                                                      |

Abbreviations: NGSS, Next-Generation Science Standards; SEP, science and engineering practices.

focused on *sensemaking*. The engineering-focused lessons instead focused on supporting students to *do* the SEPs (42%) and *engaging prior knowledge* (38%).

### *Sensemaking support*

Teachers' verbal support that helped students to build understanding of new content and concepts was coded as *sensemaking* support. Although there were similar proportions of *sensemaking* support in the Science- (54%) and computational thinking-focused (59%) Lessons and less in the engineering-focused lesson (20%; Figure 2), the *sensemaking* support was different across lessons. For example, in the computational thinking-focused lesson, teachers asked *sensemaking* questions but tended not to give students opportunities to answer or discuss their thoughts together. In contrast, during the science-focused lesson teachers engaged more frequently in expanded *sensemaking* support to help students make sense of a single new idea before moving on to a different new idea. Teachers did this by asking a question to the class and then providing support to encourage multiple, different students to respond, discuss in small groups, or consider the ideas on their own and then report back. For example, Ms. Banet led students through a whole-class discussion to help them make sense of the supplies that they were being introduced to and were about to use in an investigation:

Ms. Banet: What do the supplies represent?

Student 1: Different surfaces, like if it's grass or concrete.

Ms. Banet: Okay, different surfaces, grass or concrete. Um, [Student 2]?

Student 2: I said the concrete represents the road and the grass represents grass.

Ms. Banet: Okay, so he said it represents the road and just grass. Okay. [Name], what'd you guys say? It represents what?

Student 3: We said the sidewalk and hill.

Ms. Banet: Okay, sidewalk and hill. Alright. Anything else I'm missing? What about these supplies here?

Ms. Banet built clarifying detail through follow-up questions and students responded to each other's ideas. In the computational thinking-focused lesson, *sensemaking* support did not build the same detail as teachers asked simple questions about different new ideas back-to-back,

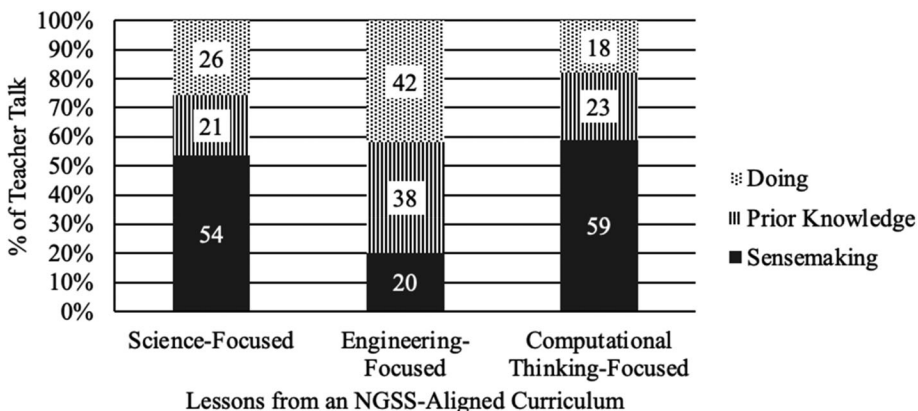


FIGURE 2 Pragmatic support across lessons

moving on after a short response from a single student. For example, Mr. Skelton led the class through a calculation procedure:

Mr. Skelton: Okay. Let us do a little, do a little table calculation over here to help you understand a little bit more about what this means. How elapsed time is equal to rain duration. Okay. For rain duration, what did we say our rain duration was going to be?

Students: 5 hours.

Mr. Skelton: Five hours. Okay. What is the elapsed time at the very beginning? How much time has passed, but like right as the rain is starting?

Students: zero.

Mr. Skelton: zero. What did we say the hourly rainfall is going to be?

Students: three-tenths of an inch.

Mr. Skelton: Okay, three-tenths. And what would be the total rainfall then? At this very point?

Student: five-tenths of an inch.

Student: wait, where y'all at?

Mr. Skelton: So the rain duration, the storm lasts for 5 hours. No time has passed. The hourly rainfall is 0.3. Remember we are at the beginning of the storm here. So how much total rainfall is there?

Here, the teacher heard responses from one student and moved on to the next question. This difference led to a larger proportion of *sensemaking* verbal support in the computational thinking-focused lesson that lacked explicit opportunities for students to participate in *sensemaking* in the whole-class discussion. This is a pattern that was observed across the activities within the science-focused and computational thinking-focused lessons.

### *Pragmatic support in the engineering-focused lesson*

From the proportions of *pragmatic* support, the engineering-focused lesson had the least amount of *sensemaking* support and far more support towards *doing* and *engaging prior knowledge* than there was in the science-focused and computational thinking-focused lessons (Figure 2). Teachers directed a large percentage of their support towards going over the project constraints in the engineering-focused lesson, especially at the beginning of each activity. For example, at the start of the engineering-focused lesson, Mr. Skelton said, "Now, keep in mind, how many squares are allotted for buildings, parking lot, the field, and the play area. You can't change those, right? So, how many spaces did you guys say for buildings?" This started a series of questions in which the teachers supported the students to remember the project constraints. The second activity in the engineering-focused lesson started in a similar manner as Mr. Skelton prompted the conversation, "Let's remind ourselves really quickly, what was [principal]'s challenge to us?" and went through a similar series of questions as illustrated previously in the RQ1 findings. The last activity in the engineering-focused lesson also started with a reminder of the constraints, as Ms. Banet said,

You guys should have sketched your first design that satisfied all of the criteria or all of the constraints. So as far as having what you guys decided: four squares for parking, five squares for a grassy field, two squares for a play area and then five squares accessible or seven squares accessible for students in wheelchairs. Four, five, three, seven. That's what it should be. four, five, three, seven.

Thus, all three activities in the engineering-focused lesson began with the teachers supporting students to recall their *prior knowledge* of the project constraints.

When offering *pragmatic* support towards *doing* in the engineering-focused lesson, teachers were mostly telling students explicit instructions about what to do. For example, Ms. Banet said,

So, I kinda just want to clarify it for everyone. So first is, let us just say that this is my first design. I'm going to put design 1. So the criteria that are here are what you have to have. Your five buildings can go anywhere, You just have to have five. So for instance, I might choose to put all my buildings here. Now parking lot. You have to have four parking lots. So I might put my parking lots over here near the buildings. But after identifying where my parking lots are, you have to say what kind of material you want it to be. I might want a permeable concrete. Or you could use standard concrete. Grassy fields you have to have four. You might choose, for soccer, I want to have artificial turf. We're going to put a turf. But then for the football field, I want regular grass. Do you guys see what we are doing now?

This is an example of the teacher giving the students explicit instructions, rather than leaving room for students to do the work independently, as was more common in the science-focused lesson. For example, in the science-focused lesson, Mr. Skelton said,

I would like for you to go to 4.2 and I would like for you to revise your predictions. How do we know how much water is soaked in by different materials? You made predictions in 4.1, I want you, based on the results of our investigation, revise your prediction below.

Here the teacher supported students to be able to do the activity, but he offered students the opportunity to do the activity on their own rather than telling them exactly how it should be done.

### 3.2.2 | Epistemic support

A larger percentage of *epistemic* support was found in the science-focused lesson (11%) than in the engineering- (5%) or computational thinking-focused lessons (4%; Table 5). For example, in the science-focused lesson, Mr. Skelton explained,

In science a lot of times we'll do the same experiment lots and lots and lots of times and we'll get slightly different bits of information and just like you said. We take an average because we want to find where is the center point, right?

This *disciplinary epistemic* support aimed to help students situate the practice of analyzing data (finding an average of some data) and the importance of repeated experiments within the discipline of science.

Although they were less frequent, there were examples of *disciplinary epistemic* support in the engineering-focused and computational thinking-focused lessons. For example, in the

engineering-focused lesson, Mr. Skelton said “This is really what engineers do, is they form science experiments first and then they figure out how to design a solution in many cases.” Similar to the science example, this teacher talk aimed to support students to situate their classroom activities within the larger context of the engineering discipline. This instance of support also described a purported connection between the focal discipline (engineering) and science. Similarly, in the computational thinking-focused lesson, Mr. Skelton said,

We have the ability to make models of models and we can do that using the technology that makes virtually everything. Basically just using computers, using computer models. So nowadays, nowadays when we really want to make especially expensive things, but really anything we develop a computer model to make it. I'll give you an example. A really good example is cars or airplanes or big expensive pieces of equipment. Imagine if every design they thought about, they had to create out of metal pieces, how expensive that would be to test it, to refine it, to make it better. It would be extraordinarily expensive to do that. So instead of doing that, we make a computer model and we use, we use data that they have collected, maybe from actually crashing cars and to see how safe they are for example, or um, maybe data from people, you know, riding in certain types of cars to see how comfortable they would be. And so we actually have done science experiments on cars and so we can get some data from that and then put it into our computer models. We've done science experiments on runoff, that we can put into our computer model.

In this example, the teacher aimed to help students to understand the purpose of computational modeling to test designs. Similar to the engineering example, this teacher talk identifies purported connections between the focal discipline (computation) and the other disciplines of science and engineering by describing how science experiments and computational models could be used for engineering design purposes in real world contexts.

In terms of the types of *epistemic* support, *disciplinary epistemic* support was less common in the science-focused lesson (33%), engineering-focused lesson (25%), and computational thinking-focused lesson (33%; Figure 3) than *classroom epistemic* support, which made up a majority of the *epistemic* support (Figure 3). For example, Ms. Banet told her students:

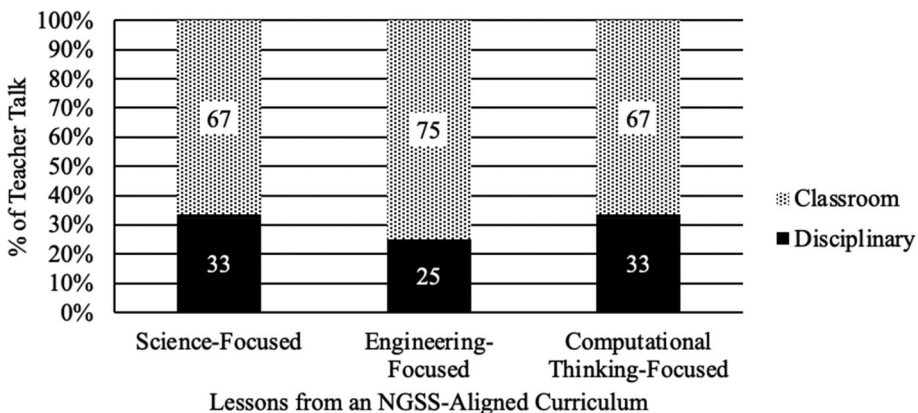


FIGURE 3 Epistemic support across lessons

Keep that thought in mind for when we move onto the actual design and we get to test different surfaces cause what you are talking about you are going to get to actually play around with and see how different surfaces react to different amounts of rainfall.

This *classroom epistemic* support aimed to help students to situate the surface material investigation within the larger project design goal.

## 4 | DISCUSSION

The results of this study describe the different ways that teachers provided pragmatic and epistemic verbal supports to help students engage with SEPs across disciplines in an NGSS-aligned curricular unit. Results illustrate the resources and assets that teachers bring to NGSS projects that integrate science, engineering, and computer science and highlight challenges that teachers may face when trying to support students' engagement in high-quality, interdisciplinary instruction as called for by the NGSS.

### 4.1 | Verbal support for focal and implemented SEPs

Results demonstrated that teachers provided the majority of support for the focal SEPs in the science-focused and computation-focused lessons. In the engineering-focused lesson teachers provided a large amount of support to help students connect to defining problems, even when it was not a focal SEP in the lesson. This difference may reflect the nature of the SEPs themselves. In the science-focused lesson, the goal was to help students understand water runoff, and the goal for the computational activities was to help students apply that knowledge to the development of a computational model. In the engineering-focused lesson, the goal was to help students generate and communicate designs, which necessarily relies on a clear understanding of how the problem is defined (e.g., design criteria). Our findings suggest that, during engineering activities, teachers may need to provide support or prompts for students to make connections between generating and communicating designs and problem definition. These findings are consistent with the benefits of instruction featuring driving questions (e.g., Krajcik et al., 1994; Weizman et al., 2010) based on anchoring phenomena (Thompson et al., 2016; Windschitl et al., 2008), which motivate students' engagement in a range of science practices. In instruction that coherently integrates science and engineering, these anchoring science phenomena are further contextualized within design problems, compelling teachers to revisit design problem definitions throughout instruction to promote student engagement, self-monitoring, and conceptual connections across disciplines (e.g., Capobianco et al., 2021). Findings are also consistent with research on responsive teaching in engineering settings where pedagogical decisions are based on what the students are saying and doing (e.g., Watkins et al., 2018; Wendell et al., 2016). Future research can work to define and distinguish the kinds of responsive supports that students may need, and teachers should provide, given the intrinsic demands of the activities from the kind of supports that teachers are offering in NGSS-based classrooms.

The teachers' actions of verbally supporting additional SEPs beyond those recommended by the Teacher's Guide for the science-focused lesson suggests the range of pedagogical resources that teachers bring to NGSS-based classrooms (Frykholm & Glasson, 2005) and illustrates the

wealth of pedagogical knowledge that is needed to enact NGSS-aligned curricula. Providing students with verbal supports for the SEPs of defining problems and using mathematics in addition to focal science practices highlights authentic connections among the SEPs. For example, integrated science and engineering design frameworks articulate how science practices (such as designing investigations, analyzing data, and developing and using models) are also engineering practices because they contribute to engineering design solutions (Burghardt, 2013; Cunningham et al., 2020; Fortus et al., 2004). Our findings also illustrate how teachers recognized students' needs in the moment and provided targeted support for these additional practices, consistent with other studies documenting the range of knowledge and skills that teachers tap to enact SEPs in NGSS-based classrooms (e.g., Kang et al., 2019). As such, our study extends previous findings from purely science contexts to instruction that integrates science, engineering, and computer science disciplines.

## 4.2 | Pragmatic verbal support

Results showed that the majority of teachers' verbal support was pragmatic (as opposed to epistemic), aimed to help students with the SEPs through doing, sensemaking, and engaging prior knowledge. This finding is not surprising, as NGSS-aligned science teaching necessarily involves supporting students to engage in sensemaking activities, build from prior knowledge, and engage in practice-based science (e.g., NGSS Lead States, 2013) in an ongoing manner.

In addition, findings demonstrate how teachers' pragmatic verbal supports differed by discipline. In the science- and computational thinking-focused lessons, teachers mostly provided sensemaking support, whereas in the engineering-focused lesson, teachers mostly provided support for doing the SEPs. This finding mirrors the extent of support for non-focal SEPs in the engineering-focused lesson and may stem from the uniqueness of engineering in this curricular context. Given the primary goal of the computational thinking-focused lesson on explaining and modeling a scientific phenomenon (water runoff), sensemaking support aligns with these overarching science goals. In contrast, the engineering-focused lesson goal of generating a specific artifact (a design solution), necessitating greater support for doing rather than sensemaking. Our findings raise new questions about what supporting sensemaking in engineering looks like in science classrooms and how such support could help build students' epistemic agency (Manz & Suárez, 2018) through student decision-making (Berland et al., 2016). For instance, engineering sensemaking support may entail teachers helping students provide rationales for design decisions and/or explain optimization practices. Future research should strive to disentangle the nature of the disciplinary goals themselves from the support students may need to reach those goals.

In addition, teachers' pragmatic supports included different opportunities for student participation in whole-class discussion. For example, teachers' pragmatic sensemaking supports for students in the computational thinking-focused lesson provided limited opportunities for students to engage in their own sensemaking as compared to in the science-focused lesson. These results may shed light on specific challenges that teachers may face when enacting interdisciplinary, NGSS-based instruction. Although teachers may have practice facilitating students' sensemaking in science, these strategies and supports may not readily translate to engineering-focused or computational thinking-focused SEPs. Thus, teachers may need support to develop similar pedagogical practices and skills across SEPs that integrate engineering and computational thinking (Cunningham & Carlsen, 2014; Dasgupta et al., 2017). Alternatively, the

differences in the types of supports could have been appropriate given the students' needs in these different disciplinary instructional contexts. Future research could provide greater insight into the dynamics of what students need in situ and how teachers' verbal supports can support students' engagement in SEPs across disciplinary settings.

### 4.3 | Epistemic verbal support

Results demonstrated that teachers rarely provided epistemic verbal supports despite the importance of building students' epistemic knowledge (e.g., Ko & Krist, 2019). Of the limited epistemic support we observed, the majority situated SEPs within the classroom context (as opposed to the discipline broadly). This finding highlights the extent to which teachers were able to help students make in-the-moment epistemic connections from the activities to the overall classroom project and, to a lesser extent, the disciplines of science, engineering, and computer science. The higher proportion of classroom epistemic support was expected given that (1) the teachers have high familiarity with the classroom materials but little authentic experience with engineering or computer science outside of the classroom and (2) the classroom materials constitute a shared experience between teachers and students (unlike disciplinary epistemic knowledge). These findings contrast with prior studies on epistemic supports for practice-based science investigations where teachers were able to successfully promote increased epistemic agency to contexts outside the classroom (e.g., Ko & Krist, 2019; Schwarz et al, 2020), possibly because the anchoring science phenomena in these studies (such as phase change and the properties of light) have broad relevance to students. By contrast, the water runoff unit from this study focused on an engineering problem defined for the teachers' and students' own school. Nevertheless, the lack of disciplinary epistemic support we observed across all of the lessons points to the need to help students and teachers situate the classroom activities within the disciplines of science, engineering, and computer science (e.g., Radloff & Capobianco, 2021; Wendell et al., 2019).

Moreover, disciplinary epistemic support provided by the teachers may be an incomplete representation of authentic professional practice, especially in disciplines relatively unfamiliar to teachers such as engineering and computer science. For example, as noted above, Mr. Skelton uses an analogy between conducting water runoff simulations and conducting automobile crash tests ("science experiments on cars"). These two activities are not completely analogous because water runoff is a science phenomenon, while an automobile is a designed artifact. Crash tests would be more precisely described as part of the engineering discipline (testing a design solution) rather than conducting a science experiment to understand a natural phenomenon. Helping students to understand distinctions among science, engineering, and computer science disciplines and how these disciplines fit together can be crucial to help students develop ideas of what it means to be a STEM professional (Pantoya et al., 2015). Further research is needed to determine how to support teachers to provide this kind of disciplinary epistemic support within interdisciplinary settings (Lilly et al., 2021).

## 5 | LIMITATIONS

Although this study only focuses on one implementation of one NGSS-aligned curricular unit, results highlight what can occur with well-supported teachers with strong science backgrounds.

The teachers in our study were different from most elementary teachers based on their undergraduate degrees in science, as only 3% of elementary teachers nationally have a degree in science or engineering (Plumley, 2019). Although these findings may not generalize to the larger population of elementary teachers, results underscore the need for more studies of how elementary teachers enact NGSS-aligned curricular materials and how disciplinary knowledge may or may not influence how elementary teachers provide pragmatic and epistemic support for students to engage in the SEPs.

Another limitation of the study is the use of classroom transcripts as the only source of data. Although the classroom implementation data provide important insight into the enactment of NGSS-aligned curricula, we can only speculate on what was observed and why teachers may have made those instructional decisions. Future studies can incorporate teacher reflections and interviews to triangulate classroom data and provide a window into teachers' reasoning. In addition, as this study only focuses on teachers' verbal support of SEPs in whole-class discussion, it does not address how these supports may or may not facilitate students' three-dimensional science learning by considering NGSS-aligned DCIs and crosscutting concepts. Future research can look to make these connections from teacher supports to student outcomes. Similarly, future work could also build on this study to consider how teachers' verbal supports may affect students' epistemic agency to have power in contributing to the ways that knowledge is developed and community practices are formed (Stroupe, 2019).

## 6 | IMPLICATIONS AND CONCLUSIONS

We recognize the challenge for elementary teachers to enact student-centered, practice-based learning approaches as called for by the NGSS (Stohlmann et al., 2012), especially because most elementary teachers do not have a strong formal background in science, engineering, or computational fields (Plumley, 2019). Thus, our results underscore the importance of helping elementary teachers undertake the important and challenging work of integrating SEPs in elementary science classrooms. We offer the following implications for professional development and educational researchers.

First, given that teachers were able to provide a wide range of verbal support for a diverse set of SEPs across three disciplines, these results illustrate the kinds of resources that elementary teachers can bring to NGSS-aligned curricula. For example, curriculum designers, teacher educators, and educational researchers can work to leverage and privilege these resources in an asset-based approach to teacher learning that builds upon the skills and knowledge that teachers bring to professional learning settings (e.g., Kang et al., 2018).

Another implication involves creating educative materials and professional learning opportunities that help teachers understand and situate science-related disciplines (e.g., through engineering design and computational thinking) to science disciplinary and real-world contexts. Given that most of the verbal support was to help students engage in the practices themselves, teachers may need additional support to help students make explicit connections from what students do in the classroom to the practices of engineers and computer scientists, as well as an epistemic understanding of the disciplines themselves. As educative materials can provide this kind of support within curricular activities for teachers (e.g., Arias et al., 2016; Davis et al., 2017) and professional learning experiences can model

and discuss enacting these kinds of supports for students (Kang et al., 2018) for science specifically, research should also consider how teachers should be similarly supported in engineering and computer science. Providing disciplinary epistemic support for engineering and computer science is necessary and important for teachers implementing NGSS-based projects to help students see themselves as potential scientists, engineers, and computer scientists (e.g., Morgan et al., 2016).

In addition, given that the same types of pragmatic supports looked different across disciplinary contexts, teachers may need support to enact pragmatic verbal supports with necessary levels of instructional depth across disciplines. For instance, educative materials and professional development can provide examples of exemplary sensemaking supports across science-, engineering-, and computational thinking-focused SEPs to help teachers potentially enact similar quality of supports across contexts. Given that this study used classroom transcripts as the sole data source, closer investigation of how teacher knowledge and instructional context may have an impact on teachers' verbal support of SEPs may help to create a more holistic picture of how and why NGSS-aligned curricula are being implemented by elementary science teachers.

In conclusion, our study illustrates ways that teachers' verbal supports for NGSS practices across science, engineering, and computational thinking in elementary science classrooms are distinct from one another. Aspects of integrated lessons that are specific to engineering and computation, such as anchoring investigations to local design problems and emphasizing the development of computational artifacts, shift both the practical and epistemic supports teachers perceive to be necessary to promote successful implementation. Teachers may need additional professional support to understand and situate engineering design and computational thinking to disciplinary and real world contexts and provide necessary pragmatic supports for each discipline.

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