Classroom Enactment of Interdisciplinary STEM+CS Curricula: Elementary Teachers' Verbal Supports in Implementation of an NGSS-Aligned Science, Mathematics, Engineering, and Computer Science Project

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by

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Approval of the Dissertation

The dissertation, Classroom Enactment of Interdisciplinary STEM+CS Curricula: Elementary Teachers' Verbal Supports in Implementation of an NGSS-Aligned Science, Mathematics, Engineering, and Computer Science Project, has been approved by the Graduate Faculty of the School of Education and Human Development in partial fulfillment for the degree of Doctor of Philosophy.

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Introduction

National frameworks promote the development and implementation of K-12 interdisciplinary curricula integrating the disciplines of science, technology, engineering, mathematics, and computer science (henceforth STEM+CS; e.g., American Society of Engineering Education (ASEE), 2020; K-12 Computer Science Framework, 2016; NGSS Lead States, 2013). Studies illustrate the potential of integrating disciplines to improve students' disciplinary content knowledge and problem-solving skills (e.g., Fllis & Fouts, 2001), increase retention in STEM+CS classes and careers (King & Wiseman, 2001; Smith & Karr-Kidwell, 2000), and provide relevant and engaging classroom learning experiences (Frykholm & Glasson, 2005; Koirala & Bowman, 2003). Interdisciplinary STEM+CS approaches also provide opportunities for students to build epistemic knowledge, which is the understanding of how and why to engage in disciplinary practices, as well as the habits of mind and nature of the individual disciplines (Berland et al., 2016; Songer et al., 2013).

To help students to build epistemic knowledge about, and engage in, STEM+CS practices authentic to that of scientists, engineers, and computer scientists (e.g., National Academy of Engineering and National Research Council 2014; National Research Council, 2012), teachers make instructional decisions about the kinds of verbal support that they enact (Barab & Luehmann, 2003; Krajcik et al., 2000; Reiser & Tabak, 2014). However, little research has explored how teachers provide verbal support in interdisciplinary contexts or the factors that inform teachers' verbal support in STEM+CS activities (Lilly, McAlister, et al., 2020).

To understand how teachers provide verbal support, many models, both discipline-general and discipline-specific, exist that articulate various elements of teachers' classroom enactment (e.g., Hamre et al., 2013; Schoenfeld, 2018; Shulman, 1986). For example, discipline-general frameworks such as Grossman (1990) and Marks (1990) describe elements such as knowledge of students' understanding, knowledge of curriculum, knowledge of instructional strategies, and knowledge of purposes as central to teachers' decision-making in the classroom. These discipline-general frameworks are intended to universally describe teaching across contexts. In contrast, discipline-specific frameworks articulate what is needed for instructional decisions in a specific discipline. For example, mathematical knowledge for teaching (Ball et al., 2008) breaks down content knowledge into content knowledge of mathematics in common settings other than teaching, specialized content knowledge that is unique to teaching mathematics, and horizon content knowledge of how distinct concepts connect. Mathematical knowledge for teaching also consists of knowledge of content and students, knowledge of content and teaching, and knowledge of content and curriculum. However few, if any, frameworks that explicitly address needs for interdisciplinary instruction.

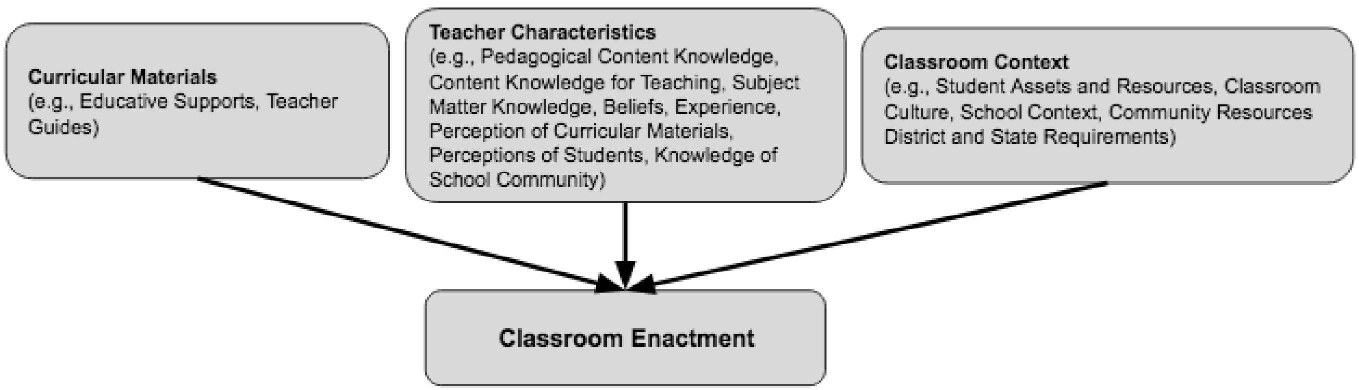
Clarifying established models with respect to both interdisciplinary contexts and epistemic supports is important. Each different discipline in an interdisciplinary curriculum has unique epistemic knowledge and practices, which presents challenges for teachers. For example, teachers must have the knowledge and skills to meaningfully teach each involved discipline (Furner & Kumar, 2007) and also to know how each discipline (including specific content, practices, and epistemologies) relates to the others. This knowledge includes disciplinary epistemic knowledge about the habits of mind, ways of thinking, and practices within each discipline and how each is similar or different from the others. Further, teachers need to support students to engage in the content and practices of multiple disciplines and intentionally make connections among disciplines (Duschl et al., 2016).

This dissertation focuses on factors that may influence how teachers use verbal supports in enactment of interdisciplinary STEM+CS curricula. We define teachers' classroom enactment to focus on what teachers actually do in classrooms in response to different classroom contexts and different perceived needs of students (e.g., pedagogical content knowledge and skill; Gess-Newsome, 2015). Teachers' classroom enactment is different from teachers' pedagogical content knowledge (PCK; e.g., Ball et al., 2008; Grossman, 1990; Marks, 1990; Shulman, 1986) that involves knowledge about teaching, including planning, reasoning, and how to teach specific content that can be captured through questioning or think-aloud protocols to understand planned strategies and rationales. PCK is often conceptualized as reflection *on* action (e.g., Schon, 1983), but teachers' classroom enactment is instead a kind of reflection *in* action. Thus, we are focusing on classroom enact as "the *act of teaching* a particular *topic* in a particular *way* for a particular *purpose* to particular *students* for enhanced *student outcomes*" (p. 36, Gess-Newsome, 2015; original italics included). This is important as research demonstrates that, even if teachers have PCK, it may not translate to enacted practice (e.g., Alfieri et al., 2015) or teachers may have not mastered specific skills to employ them effectively (e.g., Johnson et al., 2017). Thus, this dissertation also focuses on teachers' own perceptions of classroom enactment to try to understand the different factors that teachers raise as important during interdisciplinary STEM+CS instruction.

Research suggests a variety of factors that may affect teachers' STEM+CS classroom enactment (e.g., Gess-Newsome, 2015; Remillard & Heck, 2014). Figure 1 describes the factors that I focus upon in my dissertation. The following section describes each in detail.

Figure 1

Factors Affecting Curricular Enactment



Curricular Materials

Curricular materials can provide a backbone from which teachers can adopt, adapt, or innovate (e.g., Remillard, 2005). Curricular materials typically involve resources created by experts in the field that teachers can access and use (e.g., Cochran-Smith & Lytle, 1992). Curricular materials often include appropriate instructional and pedagogical strategies for particular concepts, including knowledge of potential alternative student ideas at a particular grade band. For example, an NGSS-aligned unit on scientific modeling at the fifth-grade level involves appropriate curricular materials and associated instructional strategies to support students to engage in modeling in science, engineering, and computing contexts.

To enact a curriculum, it is important that a teacher has understanding of the objectives and scope and sequence of a disciplinary curriculum along with the ability to assess the soundness of the curriculum (Gess-Newsome, 2015). A deep interdisciplinary knowledge of curriculum helps teachers to better adapt the curriculum to fit the needs of their students while maintaining fidelity to specific aspects of the curriculum (i.e., authenticity of disciplinary practices). For instance, in science, the Next Generation Science Standards (NGSS) outline performance expectations that students should be able to achieve at the end of a grade level or band. These performance expectations weave together disciplinary core ideas, science and engineering practices, and crosscutting concepts. However, the NGSS provide little guidance to teachers on how to meet those expectations in classroom instruction. Implications of teachers' not having an adequate understanding of the curriculum include that teachers may or may not be able to support connections that curriculum activities make between different disciplines or draw upon high-quality interdisciplinary resources for teaching.

Curriculum materials can include supports that teachers need to understand not only the disciplinary instructional strategies but also the nuances and differences of instructional strategies, practices, and student needs across disciplines (e.g., Davis et al., 2017; Krajcik et al., 2000). These supports are important, particularly for teachers who may not have prior experience and backgrounds in each discipline in a curriculum. For instance, teachers may choose to emphasize data tables to connect data collection and analysis practices across mathematics, engineering, and science disciplines. However, without a strong understanding of what representations are valuable and how they are used in the different disciplines, teachers may miss teaching opportunities to support students. For example, not understanding if or how a data table is useful for building a computational model may limit a teachers' use of data tables for testing and debugging computational models with students.

Some practices are similar across disciplines. For example, communicating ideas (such as through argumentation) is explicitly described across science, engineering, mathematics, and computer science. In some cases, practices in one discipline refer directly to other disciplines. For example, *using mathematics and computational thinking* constitutes a distinct scientific and engineering practice in the NGSS, reflecting instances where scientists and engineers use mathematical and computational tools and techniques to achieve their goals. Thus, in interdisciplinary instruction, teachers need to be able to weave together specific concepts, practices, and epistemic knowledge in each discipline and across disciplines for specific learning objectives. Supporting students to engage in these types of practices involves teachers' knowledge of potential challenges and alternative ideas for specific topics within each discipline, as well as how alternative ideas in one discipline may affect learning of specific topics in other disciplines. For example, students that struggle with the mathematical concept of a ratio may also struggle with the scientific concept of an absorption ratio, and then subsequently struggle to use the absorption ratio variable in a computational expression. Some frameworks articulate connections between practices across disciplines (e.g., K-12 Computer Science Framework, 2016) to help teachers to select and choose how and when to use particular practices and crosscutting concepts to help students learn particular core ideas, which includes choosing when and how to "use mathematics and computational thinking" as part of their lessons. However, teachers may not be aware of, have access to, or have help to make use of these supports.

Teacher Characteristics

Teacher characteristics can also affect classroom enactment. Teacher's PCK, content knowledge for teaching (e.g., Shulman, 1986), subject matter knowledge, and beliefs about the different domains can influence classroom enactment (Lilly, Chiu, et., 2021). Considering types of teacher knowledge in enacting interdisciplinary projects, such as those aligned to NGSS, elementary science teachers are expected to integrate disciplines (i.e., science, engineering, mathematics, and computer science) by supporting students to engage in disciplinary-specific practices, core ideas, and crosscutting concepts. To enact such projects, teachers should ideally understand concepts in each discipline, what concepts precede and follow, as well as how concepts may connect with each other across disciplines (e.g., interdisciplinary content knowledge). In elementary settings, elementary science teachers enacting NGSS-aligned curricula may need support to understand connections between disciplinary concepts across science, engineering, mathematics, and computer science. For example, elementary teachers may come into their classrooms with limited mathematics (e.g., Browning et al., 2014; Foss & Kleinsasser et al., 1996) and science (e.g., Appleton, 2008; Menon & Sadler, 2016) conceptual knowledge.

Additionally, elementary teachers may need targeted support for engineering and computer science concepts since these teachers typically have very little experience with engineering or computer science in preservice teacher programs (e.g., Webb et al., 2020; Yadav et al., 2017). In addition to understanding the disciplinary concepts in isolation, teachers may also need support to understand how concepts in different disciplines may connect or build upon each other. For example, the mathematics concept of analyzing patterns and relationships overlaps with abstraction in computer science; mathematical models using algebraic expressions to represent real-life situations can also connect to representing science phenomena and engineering concepts mathematically.

Teachers need to understand not only the epistemic knowledge of each discipline but also interdisciplinary epistemic knowledge, or how disciplines are similar and different. For example, mathematics and computation are used across fields and disciplines, but each have their own epistemic goals and habits of mind. Although the NGSS integrate science and engineering practices into one set, science and engineering are two different fields with two different goals: science investigates the natural world and engineering seeks to solve human problems in the designed world. Engineering also creates technologies that help advance scientific discovery, while science explains principles that can be applied to novel engineering solutions. These kinds of relationships are important for teachers to understand and emphasize in the teaching of interdisciplinary curricula.

As part of teacher characteristics in interdisciplinary contexts, teachers may have different beliefs and considerations of self-efficacy for different disciplines, different instructional approaches, or different self-efficacy for supporting students with individualized learning needs within different disciplines. For example, teachers may hold different beliefs about the importance of written communication in mathematics than in science, teachers' beliefs about their students' abilities may or may not vary from one discipline to another, and teachers may have beliefs regarding the capabilities of certain students to engage in specific disciplinary practices. For example, if students who face challenges in mathematics would necessarily face challenges in engineering or that students with disabilities need extensive support to engage in computer programming could result in inequitable STEM+CS opportunities for students.

Teachers' interdisciplinary self-efficacy may also affect implementation of interdisciplinary projects (Muijs & Reynolds, 2002) by causing teachers to provide unbalanced epistemic supports across disciplines or alter curricular activities in ways that reflect their self-efficacy in each discipline. For example, teachers may think a topic like computation is important to include in their classroom but not feel capable of teaching computation and, thus, emphasize computation as more of a technical process during classroom enactment rather than enabling students to create their own computational artifacts (Lilly, McAlister, et a., 2021). Alternatively, teachers may not believe specific disciplines to be as important to devote time to, because of a lack of associated state-mandated testing for that discipline, their own perceptions of the level of rigor required to engage in that discipline, or if they think that a discipline should or should not be given attention within their classroom or specific course. Through these characteristics, teachers have agency to choose how they accept, modify, and/or reject curricular materials and implement curricular materials in their own classrooms (e.g., Remillard, 2005) that may then affect the opportunities that students have to engage in certain STEM+CS practices (Askew et al., 1997).

Classroom Context

Classroom contexts, including assets and resources that students bring to the classroom, the specific school setting, community resources, and district and state requirements, can also affect how the curricular materials are enacted in classrooms. For example, a teacher in a classroom with a high percentage of students with disabilities could make an in-the-moment decision to use direct instruction directed toward the whole class as a way to explain engineering design rather than having students engage in engineering design, drawing on both the classroom context and knowledge of high-leverage pedagogical practices for special education (Therrien et al., 2017).

It is important to consider context as elementary teachers are also tasked to integrate NGSS-aligned projects into inclusive classrooms (Librea-Carden et al., 2021) that typically include students with disabilities, students without disabilities, a special education teacher, and a general education teacher. Although special education teachers can provide essential supports for students with disabilities, they often have limited preparation in STEM+CS (e.g., Taylor & Villanueva, 2017). To provide opportunities for students with disabilities to engage in NGSS-aligned projects, general education teachers typically need help to provide students with the explicit support that they may need to engage with the inquiry-based activities included in STEM+CS projects (e.g., Cook et al., 2009; Therrien et al., 2017).

Teachers also need an understanding of students' individualized learning needs to offer differentiated instruction as well as how to incorporate students' assets and resources (i.e., prior knowledge, personal skills; Gess-Newsome, 2015). Implications of teachers' knowledge of learners in interdisciplinary settings may include that teachers may have different levels of knowledge of students for different disciplines. For example, teachers may be aware of the expected mathematics background of most students following specific learning trajectories at their school and be unaware of the computer science backgrounds that some students may have access to outside of formal school settings. Thus, it may be difficult for teachers to make assumptions about what every student "knows" or has been exposed to, and teachers may or may not be able to connect to students' assets within each discipline. For example, some teachers may be better able to support students to bring in their existing assets into science instruction than into mathematics or computer science instruction.

Despite a variety of research on factors that influence classroom enactment of curricular materials, very few studies explore this within the complexity of interdisciplinary projects and privilege teacher voice. Using my framework of enactment to frame these dissertation manuscripts, I aim to describe how teachers integrate disciplines during classroom practice to help students engage in and make connections across disciplines (Duschl et al., 2016), explore teachers' perceptions of classroom enactment of an NGSS-aligned interdisciplinary STEM+CS project, and provide insight into the kinds of available knowledge, learning experiences, and supporting resources that elementary teachers feel they need in order to support enactment of interdisciplinary STEM+CS activities. To do so, I explicitly highlight the role of epistemic and interdisciplinary knowledge, skill, and enactment within classroom practice. I also acknowledge that classroom practice is based on the learning context, which includes the community in which teachers teach (i.e., school-wide or departmental policies, how to access personnel support for students with individualized needs) as well as the state and/or school-specific standards that they are responsible for teaching.

Specifically, Manuscript 1 calls for further exploration of teachers' verbal support of science and engineering practices (SEPs) through consideration of teacher knowledge bases (i.e., teacher knowledge, instructional context, teachers' beliefs). In Manuscript 2 and Manuscript 3, we strive to answer this call with our model of teacher enactment. Specifically, Manuscript 1 focuses on teachers' verbal supports in a classroom with a higher proportion of students in advanced mathematics classes across three disciplinary-focused lessons to consider equitable support for engagement in SEPs across disciplines. Manuscript 2 compares teachers' verbal support from the context in Manuscript 1 to an inclusive class context with a higher proportion of students with individualized educational plans (IEPs) and considers teachers' perceptions regarding the two differently tracked classes. Thus, Manuscript 2 considers equitable support for engagement in SEPs across disciplines for students in general and inclusive contexts. Manuscript 3 explores teachers' verbal support of interdisciplinary integration that integrates different disciplines explicitly or implicitly and teachers' perceptions about interdisciplinary practices.

Manuscript Summaries and Statuses

Manuscript 1: Elementary Teachers' Verbal Supports of Science and Engineering Practices in an NGSS-Aligned Science, Engineering, and Computational Thinking Unit

Summary

In Manuscript 1, "Elementary Teachers' Verbal Supports of Science and Engineering Practices in an NGSS-Aligned Science, Engineering, and Computational Thinking Unit", we use an embedded, single case study methodology (Yin, 2018) to examine two fifth-grade teachers' verbal supports of science and engineering practices (SEPs) as they co-teach an interdisciplinary, NGSS-aligned project across three disciplinary-focused lessons (science-, engineering-, and computational thinking-focused) within a single classroom setting. We picked this case specifically as these teachers have atypical content knowledge for elementary teachers, both holding an undergraduate degree in a field of science.

After coding verbal support in whole-class discussions for how (pragmatic) and why (epistemic) to use SEPs, we found that teachers provided verbal support for a wider range of SEPs in the science- and engineering-focused lessons, epistemic support more frequently in the science-focused lesson, and that most of the teacher support aimed to help students engage pragmatically with the SEPs through sensemaking and engaging prior knowledge. Additionally, results also demonstrate differences within the quality of the verbal support across lessons.

While the 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, limitations include that the study only focuses on classroom transcripts of whole-class discussion for one implementation of one NGSS-aligned unit. Thus, results do not include other possible forms of verbal support (i.e., small group or one-on-one discussions) and do not generalize to a larger population of elementary teachers. This manuscript then also calls for closer investigation of how teacher knowledge, the instructional context, and teachers' beliefs may impact teachers' verbal support of SEPs within the implementation of NGSS-aligned curricula.

Status

Manuscript 1 has been published by the Journal of Research in Science Teaching (JRST). This manuscript went through two rounds of revisions with JRST, major revisions and then minor revisions. I led revisions by addressing specific reviewer comments myself as well as delegating specific reviewer comments for each other author to address, setting deadlines, checking in on our progress, and resubmitting the manuscript. I was also the corresponding author and worked with the editors/publication team of the journal in finalizing the manuscript for publication. Through this dissertation, Manuscript 1 is cited as "Lilly et al., in press".

As first author, I have also led the conceptualization, data analysis, and writing of Manuscript 1. For example, I transcribed and then prepared transcripts of lessons for data analysis for Manuscript 1 and Manuscript 2 by using the Teacher's Guide to indicate when specific lessons began and ended, distinguishing which parts of transcripts were whole-class discussion, and creating spreadsheets for our IRR process and subsequent coding. I developed the epistemic / pragmatic coding hierarchy in collaboration with second author Anne McAlister to represent initial coding that we did in collaboration with third author Sarah Fick. Using the coding hierarchy, we engaged in the coding for both Manuscript 1 and Manuscript 2 at the same time as we coded the three different disciplinary-focused lessons for two different classes, blinding which class and which lesson. Specifically, Anne and I achieved IRR together and divided up and coded the remaining transcripts.

The fourth author, Jennifer (Jennie) Chiu, and I had discussions about potential papers and conference presentations and decided to focus first on teachers' verbal support within a single class and, more specifically, on the activities within the engineering-focused lesson. This became my qualifying exam, which was also an American Society for Engineering Education (ASEE) published conference proceeding that compared teachers' verbal support across the engineering activities that make up the engineering-focused lesson. Manuscript 1 significantly builds from my qualifying exam, in that we consider together teachers' verbal support in the engineering-focused lesson along with the science- and computer science-focused lessons.

As first author, I first wrote the initial text for my qualifying paper and then, following feedback from committee member Peter Youngs and author Sarah Fick, wrote the initial text for the full manuscript based on my analysis of the extended data across lessons. Next I engaged in a revision process with the other authors, including the fifth author, Kevin McElhaney, who was also the principal investigator for the larger NGSS-aligned project. I then submitted the manuscript to JRST; during the major and minor revision phases, I also worked to address feedback from my committee from my proposal defense.

Manuscript 2: A Comparison of Elementary Teachers' Verbal Supports for Students in Different Classroom Contexts During an NGSS-Aligned Science, Engineering, and Computer Science Unit

Summary

In Manuscript 2, "A Comparison of Elementary Teachers' Verbal Supports for Students in Different Classroom Contexts During an NGSS-Aligned Science, Engineering, and Computer Science Unit", I used a multiple embedded case study methodology (Yin, 2018) to examine the cases of two fifth-grade classes, one with a larger proportion of students who were in accelerated mathematics and one with a larger proportion of students with IEPs, as teachers provided verbal support throughout implementation of a four-week NGSS-aligned unit. Specifically, the embedded units of analysis are the teachers' verbal support in each of the two different classroom contexts. I picked these cases specifically as they are unique in consideration of NGSS-aligned implementation, as the same teachers in the same school are implementing the same curricular unit to two differently tracked classroom contexts, and the elementary teachers have domain expertise in science.

The same coding hierarchy is used in Manuscript 2 as in Manuscript 1, as I now compare teachers' verbal support for students to engage in SEPs across three disciplinary-focused lessons (science, engineering, and computer science lessons) in a class with a larger proportion of students who were in accelerated mathematics (Manuscript 1) to the class with a larger proportion of students with IEPs. Also new in Manuscript 2 is the use of my model of teacher enactment. Particularly, in Manuscript 2, I considered curricula materials via alignment of implemented SEPs to the recommended SEPs in the Teacher's Guide, our coding hierarchy of verbal supports within the two different classroom contexts, and teacher characteristics using surveys and interviews on teachers' perceptions of the two different class sections, classroom activities, and curriculum.

Results demonstrated that instructional decisions that teachers made in how to verbally support students may have depended upon their own knowledge of the different disciplines being integrated, their prior perceptions of students in different classroom contexts, and their in-the-moment perceptions of student needs. These factors may have led to different learning experiences for the students in each class section. Limitations to the study include that the primary data source was transcripts of whole-class discussion, which did not include other supports for integration in small group or one-on-one discussions, and that we did not consider student learning outcomes.

Based on these results, I was interested in the kinds of verbal supports that teachers may add to instruction to help students to understand the nature of science, mathematics, engineering, and computer science disciplines and how they fit together. Thus, I explored verbal support of interdisciplinary integration in Manuscript 3.

Status

Manuscript 2 is complete and has been submitted to journal review, following revisions based on my committee's feedback during the dissertation proposal process; it is currently under review. In the original analysis process, just as for Manuscript 1, the second author, Anne, and I achieved IRR and completed coding for the epistemic/pragmatic verbal support coding hierarchy that we developed based on initial coding with third author Sarah Fick. Similarly, we achieved

IRR and coded teachers' surveys and interviews to consider teachers' beliefs and views of the classes, classroom activities, and curriculum.

As first author, I wrote the initial text for my comprehensive exam engaged in revisions following the feedback from committee members Peter Youngs, Julie Cohen, and Jennie Chiu. Specifically, I worked on more closely keeping the thread of the conceptual framework throughout the methods and analysis, reorganizing parts of the paper to make the main arguments and contributions clearer, and making claims in the discussion more appropriate while also adding in stronger implications.

Additionally, I presented findings from Manuscript 2 at the National Association for Research in Science Teaching (NARST) and incorporated implications and considerations for future research based on questions from attendees following the presentation. Upon receiving feedback from the dissertation proposal process, I made additional changes (i.e., introducing a new framework) and then once again engaged in a revision process with the other authors. Through this dissertation, Manuscript 2 is cited as "Lilly et al., under review".

Manuscript 3: A Case Study of Elementary Teachers' Classroom Enactment of an NGSS-Aligned STEM+CS Project: Verbal Support of Interdisciplinary Integration

Summary

In Manuscript 3, "A Case Study of Elementary Teachers' Classroom Enactment of an NGSS-Aligned STEM+CS Project: Verbal Support of Interdisciplinary Integration," I used my model of factors that influence teachers' enactment of interdisciplinary curricula to provide background literature as well as developed an analytic framework to examine two teachers' verbal support of interdisciplinary integration as they implement a four-week, NGSS-aligned unit. Through the analytic framework, I considered a larger set of data of how teachers provided verbal support for students to integrate scientific or computational concepts and practices into three disciplinary-specific lessons (i.e., science, engineering, and computer science lessons). Within the framework, four quadrants were used to compare if interdisciplinary instructional moves are planned (i.e., documented in the curricular materials and provided to the teachers) versus added (not documented in the curricular materials) as well as if they include implicit support for integration (i.e., help students engage in practices without explicit articulation for how or why they were doing so) or if they are explicit (i.e., help students to know how and why they were integrating disciplines in their practice).

Additionally, I added a consideration of teachers' perceptions by adding an additional data source, teachers' surveys and interviews. Specifically, we identified any responses in the teacher surveys and interviews in which teachers discuss interdisciplinary curricula, concepts, or practices specifically and analyzed these to responses to consider teachers' perceptions about enacting a STEM+CS project (i.e., their perceptions of the challenges and successes of implementing interdisciplinary lessons, their beliefs about their own abilities and their students' abilities to engage in interdisciplinary practices).

Results show that, across lessons, teachers most commonly added verbal support for the integration of mathematics. In the science lesson, the majority of the instances were added and explicit; there were no instances of planned support that were made explicit. In the computer science lesson, most instances were added and implicit; planned instances were evenly split between being made explicit or implicit. Teachers also reported several challenges within less familiar disciplines, including struggling to identify and support the foundational skills that were necessary for students to engage in the engineering and computer science activities and struggling with pedagogical strategies to support students' computational modeling. Further, teachers also found it challenging when the interdisciplinary nature of the project meant that activities used concepts from one discipline in another disciplinary context.

Limitations to this study include that there may have been other supports for integration outside of whole class discussion that were not considered, including in students' workbooks, small group discussions, or in other lessons within the project. Additionally, although there were many instances of integration in this study, when we categorized the instances by disciplinary type in each lesson, there were several categories that only had a few instances. So it is also difficult to make conclusions about how each type was implicit vs. explicit or added vs. planned. Further, patterns did not emerge between the two class contexts and, thus, the contexts were not directly compared. Finally, focusing on two unique elementary teachers implementing a STEM+CS project means that results may not be generalizable to elementary teachers who do not have domain expertise in science. Future research could further consider the ways that different types of integration may be treated differently within the framework to help support teachers with different levels of domain expertise to equitably include disciplinary integration.

Status

To try out our potential framework for Manuscript 3, we coded the engineering-focused lesson using the analytic quadrants framework for both classes. In the dissertation proposal, I shared these preliminary findings based on only the engineering lesson and compared teachers' support between two differently tracked classroom contexts (i.e., one class with a higher proportion of students in advanced mathematics classes and the other class with a higher proportion of students with IEPs) as there were consistent differences. We also submitted this work to the American Society for Engineering Education (ASEE) conference. Following a round of revisions, in which we shifted our framing to include more consideration of prior research on students with disabilities, our proposal was accepted to be published in conference proceedings, and it won the 2021 Pre-College Engineering Education Best Diversity, Equity, and Inclusion Paper Award. Through this honor, we were invited to publish our findings within JPEER (Lilly, McAlister, et al., 2021). This exciting news shifted plans for Manuscript 3, which could no longer include an examination of each instance of interdisciplinary integration from the engineering lesson.

While in Manuscript 3 I do still briefly consider the engineering lesson in comparison to the science and computer science lesson, we now focus the paper on exploring teachers' verbal support of interdisciplinary integration in the science and computer science lesson along with teachers' perceptions of integrating STEM+CS disciplines. These changes to focus on only the science and computer science lessons as well as to add teacher perception data is in agreement with feedback from my dissertation committee. Additionally, given the results of the science and computer science lessons, we combine data from the two class sections instead of comparing the two class sections as there were no patterns that emerged across classroom contexts.

Following feedback from the defense process, I will submit Manuscript 3 to a journal that focuses on STEM+CS education.

Research Contribution

As national frameworks such as the NGSS and the Framework for K-12 Science Education (NGSS Lead States, 2013; NRC, 2012) encourage authentic learning experiences in science classrooms through the integration of STEM+CS disciplines, this work contributes to the currently under-researched area of how teachers support students to engage with STEM+CS practices in interdisciplinary learning activities and their perceptions and beliefs while doing so.

A goal for this dissertation is to articulate how interdisciplinary instruction complicates knowledge and resources needed for teachers' enactment of interdisciplinary STEM+CS curricula. Toward this end, the focus on classroom examples of verbal support from elementary school settings and inclusive class contexts fills a gap in the literature of NGSS-aligned curricula in elementary contexts (Crotty et al., 2017) and interdisciplinary learning opportunities for students with disabilities (Librea-Carden et al., 2021).

Overall, the dissertation works to create a more holistic picture of how interdisciplinary curricula is verbally supported by teachers and builds upon prior models of instructional decision-making (e.g., Gess-Newsome, 2015) to consider interdisciplinary contexts. Findings have implications for the support that teachers need to be able to provide the necessary verbal supports for integrating STEM+CS content and practices equitably within their elementary science classrooms. Thus, this dissertation has the potential to impact the state of knowledge in interdisciplinary learning within elementary science classrooms.

Future Work

I am interested in investigating teachers' instructional decisions when implementing interdisciplinary curricula along the lines that we suggest in the manuscripts as possible future research as well as making connections from this work to other lines of research. For example, using this same NGSS-aligned curricular unit, there are available data from later implementations. I think that it would be interesting to consider this data, as teachers have had more professional development and classroom experience, to see if instructional decisions or perceptions regarding students' abilities, the teachers' own abilities, specific disciplines or interdisciplinary curricula more broadly change. There is also data available on teachers implementing this unit in additional classroom contexts. Considering this data, I could compare the verbal support of teachers with perhaps varying levels of domain expertise in different STEM+CS disciplines and in different school contexts.

Additionally, I also interviewed students during the implementation of this project and would like to consider students' perceptions while engaging in interdisciplinary activities. This could be particularly important as students develop early on perceptions of themselves and their own abilities and identities in STEM+CS (Morgan et al., 2016). With a background in mathematics education, I also am planning to focus more directly on how mathematics can be a driving force in interdisciplinary learning and how mathematics educative materials can be incorporated within NGSS-aligned materials and implemented within elementary science classrooms, and particularly in the ways that general education teachers can be supported to do so for students with disabilities.

I also believe that supporting preservice teachers to have experiences to engage in interdisciplinary practices themselves, in implementing these practices, and in providing verbal support more broadly is important. In a shift from researching verbal support after it has taken place, I am currently working with a team of researchers across James Madison University and the University of Virginia to consider the ways in which artificial intelligence can help teachers and preservice teachers recognize more immediately the ways in which they verbally support students. I am currently supporting this work by preparing a study of preservice elementary teachers' verbal support of mathematics. I hope to continue this work by considering how preservice teachers can be helped to support mathematics within interdisciplinary instruction as well.

Finally, I am also currently leading work as the principal investigator to research teachers' perceptions and support of student engagement in interdisciplinary makerspace settings and developing future studies of teachers' support in makerspace environments. There are many parallels between this work and that of my dissertation. This will continue to be helpful, as I can take what I have studied in interdisciplinary contexts within more traditional settings and apply it to the more informal makerspace setting to continue to help teachers to support their students and offer equitable learning opportunities.

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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 sensemaking 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 four-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 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 sensemaking and engaging prior knowledge. Additionally, 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, verbal support, epistemic

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, 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 curriculum materials is through the use of verbal supports to help students engage in learning (Songer et al., 2013; Barab & Luehmann, 2003). 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 an SEP) as well as epistemological support (when and why to do an 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?

Background

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, 2009). 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.

Pragmatic and Epistemic Verbal Supports

One way that teachers can adapt 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, 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 an SEP, eliciting student ideas by engaging students' prior knowledge (*engaging prior knowledge*) with an SEP, or modeling engagement in an 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., 2020; 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., 2020). Additionally, 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.

Additionally, 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 & Rogers, 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 (Lilly et al., 2020; Ke & Schwarz, 2021). 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 & Leaderman, 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). Further, 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 & 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.

Further, 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). Additionally, 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.

Further, 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 understanding 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).

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. Further, 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.

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, four-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 five 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 one 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.

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 (b) Analyzing and interpreting data (c) Constructing Explanations and engaging in argument from evidence	(a) *Carry out investigations* and (b) *analyze data* to show how water absorption relates to surface materials and amount of rainfall. (c) *Construct explanations* by creating a claim using evidence based on their investigations and analysis (*engaging in argument from evidence*) 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 (b) Designing solutions	(a) *Generate multiple design solutions* 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) *Communicate information* 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 (b) Developing and using computational models	(a) Understand *developing computational modeling* as part of science and engineering. (b) *Interpret and test computational models* that calculate total rainfall and total water absorbed involving variables, loops, expressions, and change and set commands.

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) g*enerate 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.

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 minutes in length, so an approximate total of 10 hours 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 minutes; Engineering-Focused Lesson: 100 minutes; Computational Thinking-Focused Lesson: 130 minutes. 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.

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.

Table 2

Example of Identifying the SEPs Supported

Mr. Skelton'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. That's essentially what we did here because you guys all took data from different experiments. So we tried to find the center point. And what we found was the concrete left 13 sixteenths of an inch of water on top and only absorbed 3 sixteenths.	Using Mathematics & Computational Thinking
And then we looked at the grass. This is everybody's data. The grass only left seven twentieths on top and absorbed 13 twentieths. Now I know sixteenths and twentieths are not the same but they're close. So it does tell us still that the grass absorbed a lot more than the concrete.	Analyzing & Interpreting Data

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.

Teacher Talk Codes

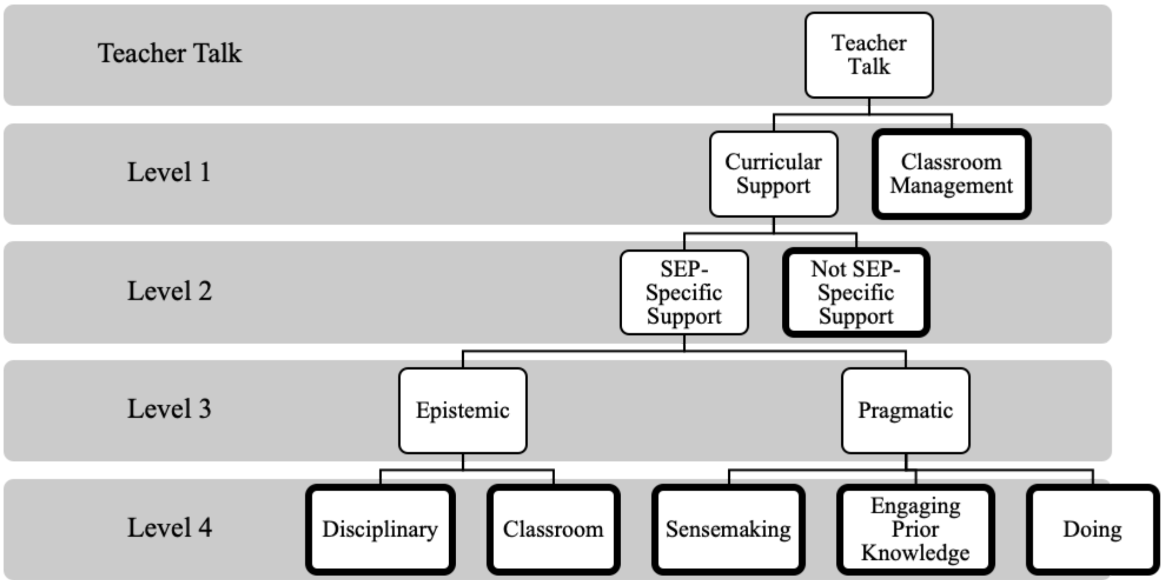
To examine how teachers supported students to engage in the SEPs through teacher talk in whole-class discussions, each teacher turn of talk was coded. As turn of talk refers to a group of sentences with a single speaker, a new turn of talk began when another person spoke or when there was a lengthy pause 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 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 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.

Figure 1

Coding Hierarchy



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 coding of *pragmatic* and *epistemic* was done 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.

Table 3

Example Codes

Codes	Definition	Examples
Epistemic		
Disciplinary	Explicitly explains how practices fit within the larger discipline	*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.* - Mr. Skelton, Engineering-Focused Lesson
Classroom	Explicitly explains how an activity fits into the larger project or orients students to the project	*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.* - Mr. Skelton, Computational Thinking-Focused Lesson
Pragmatic		
Sensemaking	Supports students to make sense of new information or build new understandings	*So did the water actually pass through the soil? What do you guys think?* -Ms. Banet, Science-Focused Lesson

Engaging Prior Knowledge	Supports students to draw upon information they had already learned	*Let's remind ourselves really quickly, what was [Principal]'s challenge to us.* - Mr. Skelton, Engineering-Focused Lesson
Doing	Models how to do a particular practice, generally in the form of instructions or a demonstration	*So you're taking your claim and your evidence and you're combining them to create your reasoning.* - Ms. Banet, Science-Focused Lesson
Not SEP-Specific	Supports students but not towards a specific SEP	*What's another reason? What else?* - Mr. Skelton, Science-Focused Lesson
Classroom Management	Focuses on facilitating movement in the classroom, calling on students, or managing behavior	*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.* - Mr. Skelton, Computational Thinking-Focused Lesson

Findings

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?

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 in order 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?

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.

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, & 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.

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:

> 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.

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.

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.

Table 5

Purposes of SEP-Specific Support Across NGSS-Aligned Lessons

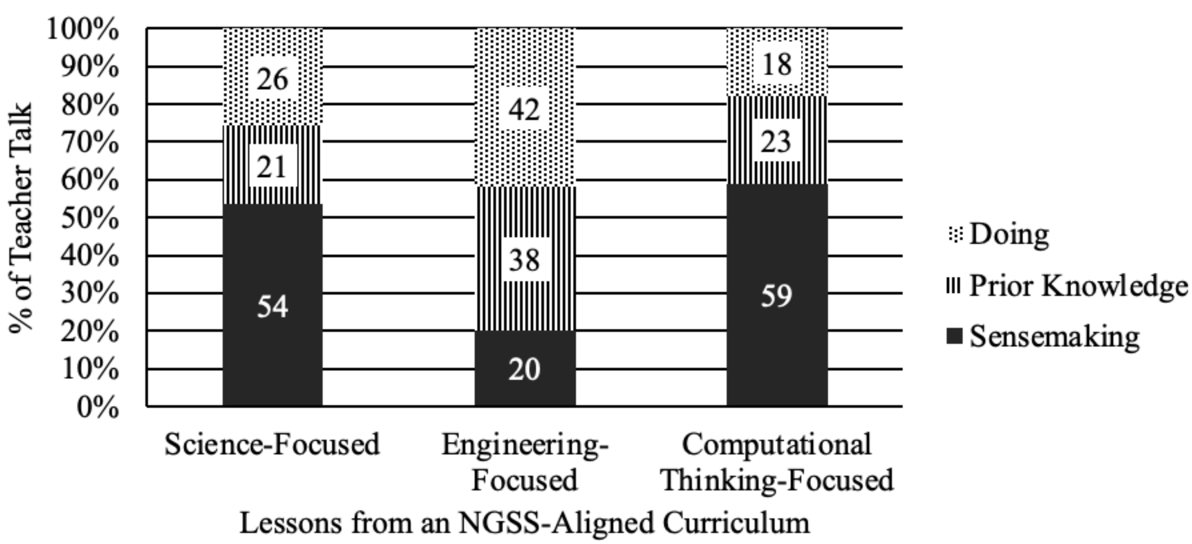
Type of Verbal Support	Science-Focused Lesson (n=179)	Engineering-Focused Lesson (n=66)	Computational Thinking-Focused Lesson (n=341)
Pragmatic	79%	67%	74%
Epistemic	11%	5%	4%

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

Figure 2

Pragmatic Support Across Lessons



Sensemaking Support. Teachers' verbal support that helped students to build understanding of new content and concepts was coded as *sensemaking* support. Though 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, 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's 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: five 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 five hours. No time has passed. The hourly rainfall is 0.3. Remember we're 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 toward 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 toward *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's 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're 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.

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've 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.

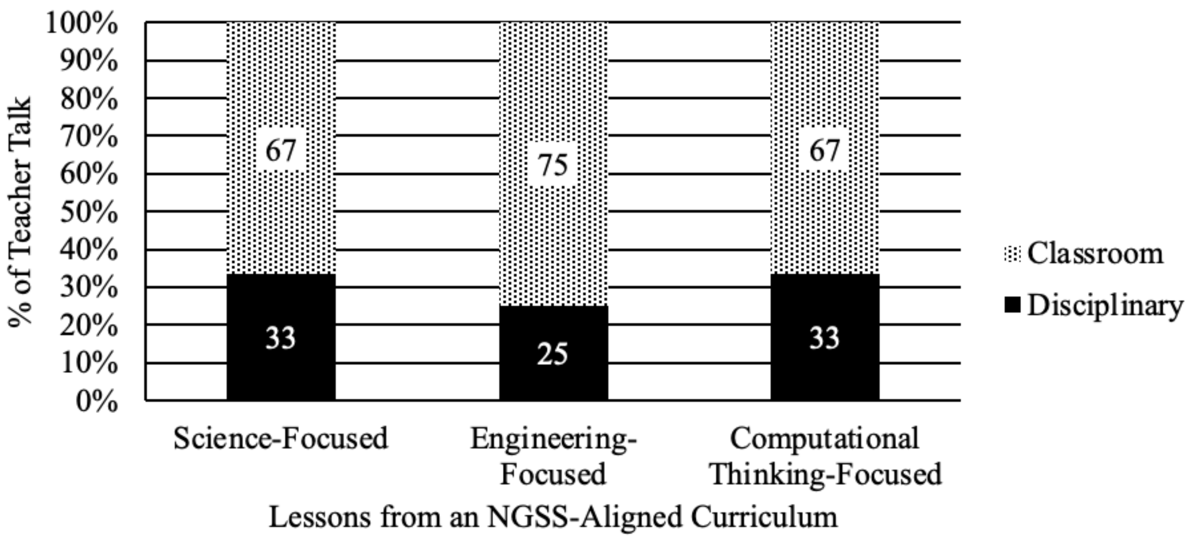
In terms of the types of *epistemic* support, *disciplinary epistemic* support was less common in the Science-Focused Lesson (33%), Engineering-Focused Lesson (25%) and Computational Thinking-Focused Lesson (33%; Figure 3) than *classroom epistemic* support, which made up a majority of the *epistemic* support (Figure 3). For example, Ms. Banet told her students:

> Keep that thought in mind for when we move onto the actual design and we get to test different surfaces cause what you're talking about you're 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.

Figure 3

Epistemic Support Across Lessons



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.

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.

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.

Additionally, 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.

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).

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 three percent 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. Additionally, 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 disciplinary core ideas 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).

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 (for example 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).

Additionally, 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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A Comparison of Elementary Teachers' Verbal Supports for Students in Different Classroom Contexts During an NGSS-Aligned Science, Engineering, and Computer Science Unit

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Abstract

This study investigates how teachers verbally support students in two different classrooms, one general education class and another inclusive class with a larger proportion of students with individualized educational plans, to engage in a Next Generation Science Standards-aligned, STEM+CS unit. Teachers' verbal support for students to understand how (pragmatic) and when and why (epistemic) to use integrated practices was examined during whole-class discussions for a four-week unit in three different disciplinary-focused lessons (i.e., science, engineering, and computer science). Daily teacher surveys and weekly teacher interviews were conducted to provide insight into the teachers' perceptions of students in each class section, classroom activities, and curriculum. Teachers reported ways in which they addressed the difficulties that they noticed students having through instructional decisions to modify their enactment of the interdisciplinary curricular materials for the Inclusive Class and discussed their rationales for these modifications. Results suggest that instructional decisions that teachers made in how to verbally support students may depend upon their own knowledge of the different disciplines being integrated, their prior beliefs of students in different classroom contexts, and their in-the-moment perceptions of student needs. These factors may have led to different learning experiences for the students in each class section. Findings then underscore the need for more research to better understand what kinds of support students and teachers need to be able to integrate engineering, science, and computer science content and practices within their elementary classrooms and provide equitable learning opportunities for all students.

Keywords: science, engineering, computational thinking, verbal support, epistemic, science and engineering practices

Reforms in science education have focused on supporting students to engage in complex practices that rely on the integration of science, technology, engineering, mathematics, and computer science (STEM+CS). Specifically, the Next Generation Science Standards (NGSS; NGSS Lead States, 2013) and the Framework for K-12 Science Education (National Research Council [NRC], 2012) recommend that teachers support students to use specific disciplinary core ideas, crosscutting concepts, and science and engineering practices (SEPs). High-quality curriculum materials (Carlson et al., 2014) and learning opportunities with engineering and computational thinking disciplines can support elementary teachers to integrate NGSS-aligned STEM+CS activities into science classrooms (Estapa & Tank, 2017).

However, because teachers' instructional decisions can affect how and what kinds of practices or activities are used in the classroom as they adapt curriculum materials to respond to students' ideas or specific classroom contexts (e.g., Remillard, 1999), equitable learning opportunities are not guaranteed by the implementation of curricular materials alone (Lowell et al., 2021). For example, teachers can encourage student engagement through the use of verbal supports (Barab & Luehmann, 2003). As suggested by the NGSS, verbal supports can help students to engage in SEPs and make tasks accessible for specific students by assisting students to use academic language, highlighting key ideas for students, changing the complexity of tasks or activities, and helping students to make connections between content and their everyday lives (Krajcik et al., 2000; Reiser & Tabak, 2014). Types of verbal support include pragmatic verbal support and epistemic verbal support. Pragmatic verbal support can help students to engage in practices that are authentic to scientists, engineers, and computer scientists (e.g., National Academy of Engineering and National Research Council 2014; NRC, 2012). Epistemic verbal supports can help students understand why and how scientists, engineers, and computer scientists engage in practices (e.g., González-Howard & McNeill, 2019; Gray & Rogan-Klyve, 2018; Ke & Schwarz, 2021; Moore et al., 2014; Russ, 2018).

However, teachers may not have ample experience or self-efficacy to provide verbal supports to students for engineering or computational thinking practices in their classrooms (e.g., Plumley, 2019). In elementary science contexts, particularly, teachers may not have the same level of experience and disciplinary expertise with engineering and computing as they do with science. For example, although many teacher preparation programs offer elementary science methods courses, engineering and computer science method courses are less common. Thus, further research is needed to capture the verbal supports that elementary teachers provide to help engage students across SEPs within NGSS-aligned curriculum (e.g., Crotty et al., 2017; Wendell & Rogers, 2013).

Additionally, very few studies investigate how these SEPs are enacted in inclusive classrooms with students with identified disabilities or individualized educational plans (IEPs). Students with disabilities can be overlooked in STEM+CS education research (e.g., Villanueva et al., 2012), and science contexts are often understudied in special education research (e.g., Therrien et al., 2011). Research also documents disparities among K-12 STEM+CS experiences for students with disabilities, as students with disabilities may have less opportunities and access to STEM+CS content and courses (U.S. Department of Education, 2014, 2018), and inquiry- or project-based learning can be somewhat at odds with effective teaching practices for students with disabilities (Therrien et al., 2017). Thus, it is imperative to understand how to help elementary teachers support students with disabilities within inclusive classrooms to engage in

NGSS-aligned curricula that integrate STEM+CS disciplines and are project-based.

This paper explores how teachers support students to engage in SEPs in an NGSS-aligned science, engineering, and computer science curriculum and compares verbal supports across general and inclusive class sections. This case study specifically focuses on how two co-teachers provide pragmatic and epistemic verbal supports to help students engage in SEPs in an NGSS-aligned, STEM+CS interdisciplinary curriculum unit. We address the following research questions:

RQ1: Which SEPs did teachers support in whole-class discussions in inclusive and general class contexts, and to what extent were the supported SEPs in each class aligned with the intended SEPs suggested in curricular materials?

RQ2: What differences, if any, were there in how teachers used pragmatic and epistemic verbal supports for SEPs in whole-class discussion for inclusive and general class contexts?

RQ3: What kinds of rationales did elementary teachers report for making instructional decisions within inclusive and general class contexts?

Through this case study, this paper aims to to provide insight into how to support all students to equitably engage in NGSS-aligned curricula at the elementary level by describing how teachers' knowledge of different disciplines, prior beliefs of students in different classroom contexts, and perceptions of student needs may contribute to teachers' verbal supports to engage students in SEPs during NGSS-based instruction.

Background

NGSS-Aligned Curricula

Despite a national emphasis on integrating engineering, science, and computer science practices and concepts in science classrooms (NGSS Lead States, 2013), there is not a single, agreed upon definition of what counts as interdisciplinary STEM+CS at the elementary level (e.g., Breiner et al., 2012; Estapa et al., 2017; NRC, 2014; Roehrig et al., 2012). Instead, there are many commonly accepted models of interdisciplinary STEM+CS exist (Johnson et al., 2020) that are context-dependent (Bybee, 2013) or dependent on the stakeholders involved in the integration (Breiner et al., 2012). We define interdisciplinary STEM+CS curricula as curricula that interweaves practices and concepts from science, engineering, mathematics, and computer science disciplines through building connections between these different disciplines and real-world problems within a single classroom environment (Stohlmann et al., 2012). The interdisciplinary STEM+CS curricula considered in this study, specifically, is aligned to the NGSS, which may encompass ideas or strategies that are atypical in K-12 science teaching (e.g., Davis et al., 2019).

Several large shifts in thinking about science teaching are represented by the NGSS standards, here we focus on two. First, STEM+CS concepts are integrated together within the disciplinary core ideas (DCIs), science and engineering practices (SEPs), and crosscutting concepts (CCCs). For example, the DCIs include both the big ideas of science as well as the big ideas of engineering. Across both disciplines, these big ideas have been whittled down to those that have explanatory power for multiple phenomena, a response to the critique of previous standards that were described as “a mile wide and an inch deep.” Mathematics and computer science are represented as SEPs in Developing and Using Models, Analyzing and Interpreting Data, and Using Mathematics and Computational Thinking. Within the CCCs, mathematics is included in the use of Scale, Proportion, and Quantity, Conservation of Energy and Matter, and Patterns. In ways not articulated in previous standards, the NGSS then brings together STEM+CS disciplines as complementary components of developing understanding of natural phenomena and designed systems.

Second, the NGSS focus on supporting students to engage in and use SEPs to develop science explanations and engineering design solutions. The NGSS represent this coordination of content and practices through the combination of DCIs, SEPs, and CCCs into single performance expectations. Berland and colleagues (2016) describe this as a move towards meaningful use of the SEPs, where students are supported to understand both how and why to use the SEPs to make sense of science phenomena and support engineering design in coordination with CCCs.

These two shifts in the standards have created a need to support NGSS-aligned teaching and learning. While substantial research has examined the teaching practices required to support student engagement in science practices integrated with disciplinary core ideas (e.g., McNeill & Krajcik, 2008; Windschitl et al., 2012), this approach to teaching has not been broadly realized in practice (Smith, 2020), especially for STEM+CS curricula. The lack of available curriculum materials that are aligned to the NGSS is a challenge to implementing NGSS-aligned instruction (Carlson et al., 2014). Another struggle with enacting NGSS-aligned curriculum materials is a need to help teachers identify and practice the pedagogical shift required to support students to both engage in the SEPs and to understand why they are using the SEPs to answer questions and design solutions (Banilower et al., 2014; Lowell et al., 2021). Thus, this study investigates the kinds of verbal supports that teachers use to help students engage in NGSS-aligned, integrated STEM+CS curricula.

Verbal Supports

While written supports and scaffolds are often included in curriculum materials by the curriculum developers, an additional set of supports and scaffolds are provided by the teachers during instruction, including verbal supports. Verbal supports can focus on difficult concepts (Duschl & Osborne, 2002), engagement with science practices (McNeill & Krajcik, 2008), or the framing of curricular activities (Berland et al., 2016; González-Howard & McNeill, 2019). In implementation, the framing of these verbal supports may be determined by the teachers' knowledge of their own students including students' interests, knowledge, and abilities.

When focusing on students' engagement with SEPs and curricular activities, research suggests at least two types of verbal supports that teachers may offer. The first type is *epistemic* verbal support that helps students to develop knowledge of the nature, thinking, and practices of disciplines as well as to understand how their engagement with SEPs in academic work fits within the practices of that discipline (Lilly, McAlister, et a., 2020; Ke & Schwarz, 2021). Prior research, has often focused on how teachers can support students to build epistemic knowledge in science, engineering, and computer science (e.g., González-Howard & McNeill, 2019; Lin & Chan, 2018; Tan et al., 2019) separately rather than in interdisciplinary contexts. Further research in interdisciplinary contexts is important as teachers can still utilize epistemic supports to help students to build understanding of each discipline being integrated (e.g., Tytler et al., 2021) but can also help students to understand how practices, such as SEPs, are authentically used across multiple disciplinary contexts (Ke & Schwarz, 2021). In this study, epistemic verbal supports include the ways that teachers can use verbal supports to both help students to learn about the nature of a discipline (e.g., Lazenby et al., 2020) and the purpose of SEPs in scientist, engineer, or computer scientist professions (*disciplinary*) as well as to help students to build understanding of the purpose and motivation of disciplinary activities in their school contexts (*classroom*; e.g., Berland et al., 2016; Sandoval, 2004).

To support students to understand the nature, ways of thinking, and practices of a discipline, teachers can explicitly make connections (e.g., Berland et al., 2016; Lederman et al., 1992; Moore et al., 2014) to and across science, engineering, and computer science disciplinary professions to help students to build understanding of how the goals of a discipline can be supported by engagement in disciplinary practices (Gray & Rogan-Klyve, 2018). In NGSS-aligned units, disciplinary epistemic verbal supports can include teachers supporting students to understand the nature of science (e.g., Abd-El-Khalick & Leaderman, 2000), engineering (e.g., Moore et al., 2014), and computer science (e.g., K-12 Computer Science Framework, 2016) as well as how disciplinary practices are defined within science (Kelly, 2008), engineering (ASEE, 2020), and computer science (K-12 Computer Science Framework, 2016) communities.

To support students to understand the importance of engaging in SEPs within their classroom context, classroom epistemic verbal supports can include teachers helping students by motivating how and why engaging in specific SEPs through classroom activities builds their disciplinary knowledge (Russ, 2018) as well as fits into the goals of larger projects or coursework (Berland et al., 2016; Sandoval et al., 2016). In an NGSS-aligned unit, an example of a teacher's classroom epistemic support is helping students to understand how creating and using mathematical models of the scientific phenomenon of water runoff to test different design solutions can support them to address the problem of how to reduce water runoff at their school.

A second type of verbal support is *pragmatic* support to directly help students engage in disciplinary practices (e.g., Lilly et al., in press). Pragmatic verbal support involves teachers focusing on helping students to engage in the practices themselves, making the invisible aspects of the practice visible and breaking down large tasks into smaller pieces (Reiser & Tabak, 2014). In this study, pragmatic supports include ways in which teachers provide verbal support to help students to engage in SEPs by making sense of new information (*sensemaking*), eliciting and utilizing students' prior experiences and understandings (*engaging prior knowledge*), and modeling activities through demonstration and specific instruction (*doing*).

To support students to make sense of new information, teachers can use pragmatic verbal supports to help to build new understanding and knowledge while using the SEPs (e.g., McNeill & Krajcik, 2008). In an NGSS-aligned unit, examples may include teachers supporting students to understand how mathematical and computational models represent scientific ideas and phenomena (e.g., Hutchins et al., 2020) and can be used to test potential designs (e.g., Dasgupta et al., 2017) as well as to develop new understandings based on the evidence of these tests (Odden & Russ, 2019).

To engage students' prior knowledge, teachers can use pragmatic verbal supports to elicit and utilize understandings about content, ideas, and past experiences from their students. In an NGSS-aligned unit, examples of pragmatic support for engaging prior knowledge could include helping students to reflect back upon science (e.g., Bransford et al., 1999) and other disciplinary knowledge (e.g., Shaughnessy, 2013) learned in academic contexts, knowledge learned outside of academic contexts (e.g., Linn & Eylon, 2011), or knowledge from earlier parts of the curricular unit.

To support students to engage in doing SEPs, teachers can use pragmatic verbal supports to help students understand specific instructions or steps necessary to authentically engage in the practices. In an NGSS-aligned unit, examples could include giving students instructions on how to create different versions of potential designs (Luo, 2015) as well as modeling how to revise these designs following the results of design tests (Wendell & Lee, 2010) to create solutions to questions about the natural world (Davis et al., 2019).

However, particularly for elementary teachers, supporting students may be difficult as these teachers may not have learned or have prior experience with NGSS-aligned science curricula or formal backgrounds in science, engineering, or computer science (Davis et al., 2019; Plumley, 2019). Teachers may then struggle to provide pragmatic verbal supports if they are unable to make sense of information themselves, are not aware of what prior knowledge students may have to be elicited and engaged, lack experience engaging in specific disciplinary practices themselves let alone have knowledge of how to support students to engage in these practices, or doubt their own capabilities in implementing disciplinary-tasks. Teachers may then also struggle to provide epistemic verbal supports if they do not have an understanding of how to make connections between classroom activities and specific disciplines as well as across disciplines.

In this study, we define verbal support as epistemic when teachers provide opportunities for students to make connections to disciplinary professions or to understand the purpose of curricular activities within the classroom; we define verbal support as pragmatic when teachers help students to engage in the SEPs by making sense of new information, eliciting prior knowledge, or demonstrating and specifically instructing how to engage in an SEP. Researchers suggest that this dichotomy of epistemic and pragmatic support is required for both SEPs (Berland et al., 2016) as well as CCCs (Lilly, McAlister, et al., 2020). Further, considering how teachers provide both pragmatic and epistemic support across disciplines is important because SEPs may encompass different knowledge and processes within different disciplines. For example, a single SEP includes epistemic goals for two different disciplines, asking questions for science and defining problems for engineering (Cunningham & Kelly, 2017). The ways in which teachers are able or willing to verbally support students' epistemic understanding of the different purpose of this SEP across these different disciplines may then affect students' opportunities to pragmatically engage in this SEP for different disciplinary-focused activities.

However, little research has examined how epistemic and pragmatic supports are used by teachers to support students in different classroom contexts. Our study considers how a teacher team, within the same school context and using the same curricular materials, support students in two different classroom contexts in order to further our understanding of how to help teachers equitably support students to engage in NGSS-aligned, STEM+CS curricula in elementary science classrooms.

Inclusive Classrooms

Elementary teachers are also tasked with the challenge of implementing these NGSS-aligned STEM+CS curricula in inclusive classrooms (Librea-Carden et al., 2021). Inclusive classrooms typically involve students with disabilities, a special education (SPED) teacher, a general education teacher, and students without disabilities. SPED teachers teach multiple content areas and provide complex support to students, but often have limited

STEM+CS preparation (e.g., Taylor & Villanueva, 2017). Similarly, general education teachers often need support to provide opportunities for students with disabilities to engage in STEM+CS instruction (e.g., Cook et al., 2009). For example, research demonstrates that students with disabilities may need explicit support in order to engage with practice-based science activities (e.g., Therrien et al., 2017) and similarly engage with science, computation, and engineering practices. However, explicit support does not necessarily mean that instruction is not student-centered, but instead that expectations, behaviors, and processes are explicitly articulated (Therrien et al., 2017).

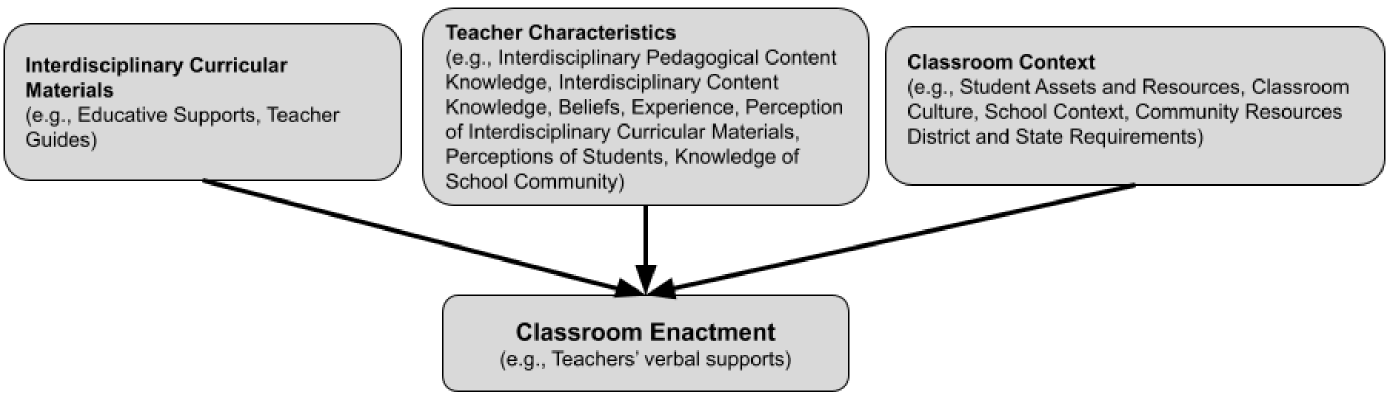
Despite the importance of supporting all students to engage in STEM+CS, little research has considered how teachers' implementation of STEM+CS curricular materials may differ depending on the context of the classroom or teachers' beliefs about the disciplines and students they are teaching (Gess-Newsome, 2015). Further, little research, if any, investigates how elementary teachers make instructional decisions to verbally support students to engage in STEM+CS units in inclusive contexts. Such research may be particularly important in the context of elementary classrooms, as elementary teachers rarely have prior experience teaching with, or knowledge about, engineering or computer science and may need support to integrate these disciplines into elementary science classroom settings (Purzer et al., 2014). Thus, this study investigates the types of verbal supports that elementary teachers enact in general and inclusive classroom contexts.

Planned and Enacted Curricular Materials

To examine the kinds of verbal supports that teachers use during instruction, and how the supports may change in response to different class contexts, we explore differences in planned versus enacted STEM+CS curricula (e.g., Capobianco & Rapp, 2014). Building upon other models of professional knowledge and classroom enactment (e.g., Gess-Newsome, 2015; Remillard, 2005), we consider different factors that can influence how teachers take up curriculum materials for use in classroom instruction (Figure 1).

Figure 1

Model of factors that influence classroom enactment and teachers' verbal supports.



Interdisciplinary Curricular Materials

First, high-quality curricular materials are a crucial factor in classroom enactment of NGSS-aligned, STEM+CS instruction (e.g., Holthuis et al., 2018; Lowell et al., 2021). Interdisciplinary curricular materials include educative materials aimed to help teacher learning by developing interdisciplinary content knowledge, epistemic knowledge, knowledge of students, and curricular knowledge, for example (e.g., Davis et al., 2017). High-quality STEM+CS curricular materials also involve knowledge of appropriate instructional strategies for particular concepts, including knowledge of potential alternative student ideas at a particular grade band. Curricular materials can also provide explicit examples of pragmatic and epistemic verbal supports that teachers can use during enactment. For example, high-quality, NGSS-aligned curricular materials for scientific modeling at fifth grade can include explicit examples of pragmatic verbal supports to help students engage in modeling in and across science, engineering, and computing contexts.

Teacher Characteristics

Teachers also have agency to choose how they accept, modify, and/or reject curricular materials and implement professional knowledge in their own classrooms (e.g., Remillard, 2005) thereby creating and modifying the opportunities that students have to engage in certain practices (Askew et al., 1997). Teacher characteristics, including disciplinary and interdisciplinary pedagogical content knowledge, beliefs and orientations, and perceptions of students, may then influence how curricular materials are enacted in classrooms and the ways that verbal supports are provided.

First, we consider two types of knowledge. One type of knowledge, individual pedagogical content knowledge, is knowledge about teaching a specific discipline that is held by individual teachers (e.g., Ball et al., 2008; Grossman, 1990; Marks, 1990). Another type of knowledge, interdisciplinary pedagogical content knowledge, is a teacher's knowledge about teaching disciplines in integrated ways and supporting students to understand the ways in which the specific practices of a discipline can be used in service of the practices of a different discipline (Lilly, Chiu, et al., 2021). For example, when enacting a STEM+CS activity, teachers can pull upon their interdisciplinary pedagogical content knowledge to support students to understand how they can use computational models to test their engineering designs. These types of knowledge can influence what teachers choose to enact from existing curricular materials (McNeill & Krajcik, 2008).

Teachers' beliefs and orientations include their own ways of thinking and attitudes about teaching, beliefs and attitudes about the disciplines that they teach, and the students that they teach (e.g., Muijs & Reynolds, 2002). For example, a teacher may hold different beliefs about the importance of engineering or computational domains and their ability to teach and support them, or hold different beliefs about general and inclusive classrooms that then may affect what kinds of verbal supports they choose to enact in their classrooms.

Finally, teachers' prior experiences and understanding of problem-based and practice-based instruction can inform teachers' characteristics (Figure 1). For example, teachers' access to professional education in support of the NGSS, through preservice opportunities and professional development, can influence teachers' agency in enacting interdisciplinary curricular materials (e.g., Christian et al., 2021; Hayes et al., 2019).

Classroom Context

Similarly, the classroom context plays an important role in how teachers enact curricular materials. Teachers can draw upon different assets and resources that individual students bring to classes to tailor learning opportunities within individual classes (e.g., Mejia et al., 2020; Shelton, 2021). The school context surrounding the classroom can have a large influence on classroom enactment in terms of leadership, accountability structures, and resources for interdisciplinary instruction. Moreover, whether or not a state has NGSS standards and the priorities of the school and district can also affect how teachers choose to enact NGSS-aligned curricular materials (e.g., Lilly et al., in press), which can then affect the kinds of verbal supports that teachers choose to use during enactment. Similarly, a school with a focus on strict classroom behaviors and management practices might have a harder time supporting the student-student conversations emphasized by the NGSS.

Classroom Enactment

Thus, this study aims to describe how teachers enact STEM+CS, NGSS-aligned curricular materials. In particular, this study seeks to understand to what extent teachers verbally implement supports provided within NGSS-aligned curricular materials during classroom enactment to integrate SEPs across general and inclusive classroom contexts. This study builds upon a previous case study that investigated the nature of verbal support in a general classroom context (Lilly et al., 2022) to compare verbal supports across general and inclusive classrooms across science, engineering, and computational lessons.

By investigating how teachers enacted a NGSS-aligned unit across two different classroom contexts, we work to highlight the kinds of skills that teachers may require to engage in the important, but challenging, work of integrating science, engineering, and computer science within and across elementary science classrooms, as well as provide insight into the kinds of factors that may affect enactment of curricular materials. Goals of the study include informing professional development and other learning opportunities to help elementary teachers implement equitable NGSS-aligned instruction across contexts.

Research Design

Settings and Participants

Using a multiple embedded case study methodology (Yin, 2018), we examine the cases of two fifth-grade classes engaged in a four-week NGSS-aligned unit. The two classes were located in a public elementary school in the southeast United States. School-wide, students were 38% Black, 13% Hispanic, 38% White, 6% Asian, and 5% Multiple Races; 17% of students were Emerging Bilinguals and 53% qualified for free or reduced-price lunch. Similar student percentages were represented in both of the classes considered in this study. Year-long administrative placement of students in the two classes, the General and Inclusive Classes, was based on student achievement in mathematics as well as accommodative placement in an inclusive classroom. Thus a larger proportion of students who were in accelerated mathematics were in the General Class, and the Inclusive Class had a larger proportion of students with IEPs.

In this multiple case study, the embedded units of analysis are the teachers' verbal support in each of the two different classroom contexts. The classes were co-taught by the same two teachers, Mr. Skelton and Ms. Banet (pseudonyms), who both have more than five years of teaching experience. During the facilitation of this study, Mr. Skelton was the STEM coordinator for the elementary school and Ms. Banet was a fifth-grade math and science classroom teacher. Both teachers had domain expertise with science backgrounds, as they each hold an undergraduate degree in a science field. Additionally, both teachers had knowledge of the unit's goals and embedded educative supports as both were co-developers of the implemented unit, had piloted the unit together the previous year, and had attended at least four monthly meetings and one week of professional development to learn more about NGSS, engineering, and computation. The cases in this study are unique in consideration of NGSS-aligned enactment, as the same teachers in the same school were implementing the same curricular unit to two different classroom contexts, and the elementary teachers had domain expertise in science.

On occasion, there was a SPED teacher present in the Inclusive Class. However, the SPED teacher did not contribute to whole-class discussion during the NGSS-aligned unit but provided targeted support for specific students with disabilities within the classroom while they worked on individual tasks. Thus, the SPED teacher's verbal support was not considered in this study focused on whole-class discussion.

Data Sources and Analysis

Interdisciplinary Curricular Materials: Teacher's Guide

In the NGSS-aligned, interdisciplinary unit, students were challenged to consider the design criteria of parking requirements, grassy fields, accessible play areas, and budget constraints while redesigning their school grounds to reduce water runoff. The curricular unit had been co-developed and refined with Mr. Skelton and the STEM district coordinator through a pilot implementation in the same context the year prior (Chiu et al., 2019). Three of the thirteen total lessons in the unit were examined in this study, chosen for their discipline-specific content foci (science, engineering, and computer science, respectively).

In this study, the teachers had access to interdisciplinary curricular materials through the Teacher's Guide. The Teacher's Guide for the unit contained both the student activities as well as interdisciplinary pedagogical strategies for teachers. Specifically, the Teacher's Guide included pedagogical strategies that were linked to specific SEPs and offered suggestions for how teachers should enact learning performances across activities. To analyze the Teacher's Guide, two researchers, in collaboration with the curriculum developers, read and discussed the Teacher's Guide together to determine the focal SEPs for each lesson. We describe these focal SEPs, italicized with their learning performances, below.

The science lesson included six science activities and suggested learning performances for students to show how water absorption relates to surface materials and amount of rainfall (*carrying out investigations* and *analyzing data*) and using data as evidence to create a claim that answers a question (*constructing explanations*). In the engineering lesson, the Teacher's Guide suggested learning performances across three engineering activities, including students comparing their multiple design solutions (*generating multiple design solutions*) in order to determine which solution best reduces the amount of water runoff and meets the design criteria and presenting their engineering design solutions and the process used to develop these solutions (*communicating information*). In the computer science lesson, the suggested learning activities were to be implemented across three computer science activities that included students building an understanding of variables and creating loops and set commands (*develop computational models*) to create models that would calculate the total rainfall and total water absorbed (*interpret and test computational models)*. In our analysis of enactment of teacher verbal support, we expected teachers to support students in these focal SEPs.

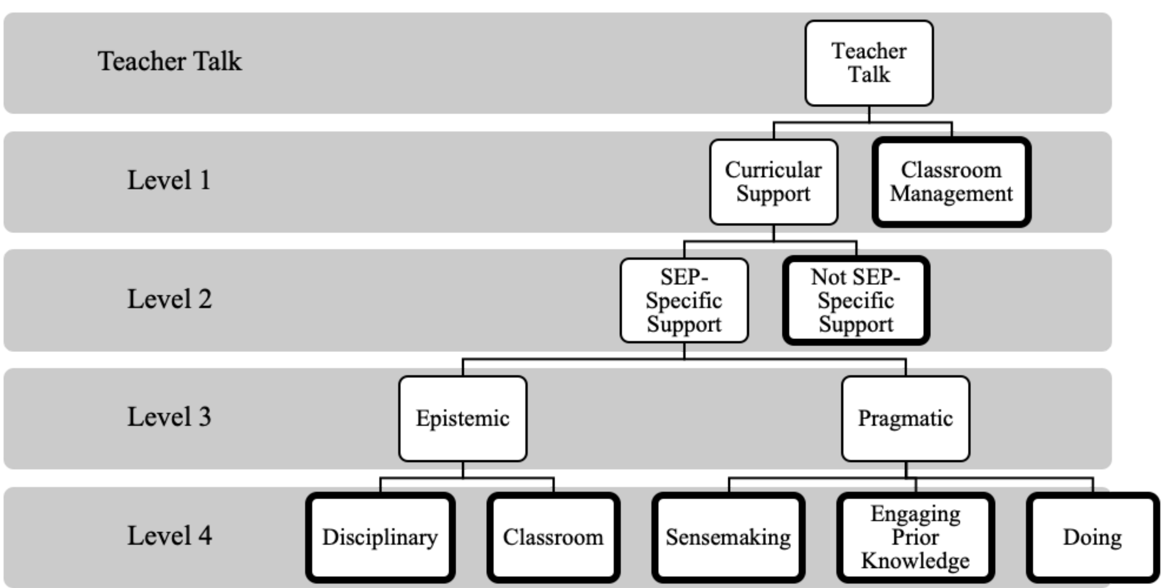
Classroom Enactment: Verbal Supports

To explore classroom enactment through teachers' verbal supports, audio recording devices were placed in the classroom to capture instances when the teacher addressed the whole class for each lesson. These recordings of whole-class discussions were transcribed and analyzed for each lesson. Additionally, the transcripts of each lesson provided information about the context of the specific activities happening in the classroom and insight into teachers' verbal supports as they noticed what was happening in the classroom and made decisions. Prior to coding, transcripts were blinded so that researchers did not know whether the class context was inclusive or general.

Using the transcripts, two researchers coded each turn of talk spoken by a teacher in whole-class discussions (Figure 2). Each turn of talk was a chunk of sentences with a single speaker, which started and ended when a different person spoke or if there was a long pause. Codes were applied to turns of talk rather than single sentences because the teachers' verbal support was often built through several sentences in a turn of talk. Each of the teacher turns of talk was coded with one or multiple codes applied from each level of the codebook (Appendix, Codebook). Thus, although we report the counts for transparency of our data and analysis, we chose to focus our findings on the proportions of teacher talk based on the coding hierarchy (Figure 2).

Figure 2

Coding Hierarchy



Researchers first used the first-level codes *curricular support* and *classroom management* to code each turn of talk in which the teacher was the speaker (Miles et al., 2020). *Curricular support* included all turns of talk in which teachers verbally clarified concepts or activities to support students to engage with the curriculum in ways that they might not have otherwise been able to do. *Classroom management* included all teacher turns of talk in which there was not an instance of *curricular support*, but instead teachers were doing things such as managing behavior, talking about logistics, or calling on students.

For turns of talk that were coded *curricular support*, researchers considered if the turn of talk was *SEP-specific support* or if the talk was not in support of a specific SEP (*not SEP-specific support*; Level 2, Figure 2). To code a turn of talk as *SEP-specific support*, researchers had to be able to identify and agree upon which SEP was being supported. They then noted if it was a focal SEP as suggested by the Teacher Guide for that particular lesson or an SEP that teachers were additionally supporting in implementation. When a turn of talk did support students but not towards a SEP, such as when the teacher reframes a question or extends the large group discussion, it was coded as *not SEP-specific*.

Turns of talk that were *SEP-specific support* were then coded as *epistemic* if they supported students to think epistemically about the SEPs and connect the classroom activities to broader purposes, while turns of talk that supported students to engage in and make sense of the SEPs were coded as *pragmatic* (Level 3, Figure 2). Both codes could be applied to the same turn of talk if both forms of support were present.

Finally, third-level codes categorized teacher talk as *epistemic* or *pragmatic. Epistemic* turns of talk were coded as *classroom* if the turn of talk supported students to think about how an

SEP fit into the overall project, and *disciplinary* if the turn of talk supported students to think about how an SEP fit into the discipline of science, engineering, or computer science (e.g., Berland et al., 2016). Both codes were applied to the same turn of talk where appropriate. *Pragmatic* turns of talk were coded as *sensemaking* if the teacher was supporting students to understand and make sense of new ideas. They were coded as *engaging prior knowledge* if the teacher was supporting students to draw upon information they had already learned. Finally, *pragmatic* turns of talk were coded as *doing* when the teacher supported students through instruction or modeling of how to perform a SEP. Multiple codes were applied to the same turn of talk where appropriate.

In order to establish reliability, three researchers coded 5% of the data to refine code definitions and come to agreement. They then coded the next 5% with the refined code definitions until agreement greater than 85% was obtained across 20% of the data (Miles et al., 2020). After establishing reliability, the remaining data was coded independently by two of the researchers using the final version of the codebook (Appendix, Codebook). The two coders met to discuss any coding uncertainties throughout the remainder of the coding.

The entirety of each lesson was included as data, and each lesson was treated as a case (Yin, 2018). Each lesson spanned several class periods, and each class period was fifty minutes. Specifically, the science lesson spanned three class periods in the Inclusive Class and four class periods in the General Class, the engineering lesson occurred over three days for both class sections, and the computer science lesson lasted four days for the Inclusive Class and five days for the General Class. Thus, ten class periods (approximately eight hours) were analyzed for the Inclusive Class and twelve class periods (approximately ten hours) were analyzed for the

General Class. Throughout each lesson there were varying amounts of whole-class discussion. As a result, the number of instances of teacher talk that were coded as curricular support varied across the lessons (i.e., Inclusive Class: Science: 177, Engineering: 74, Computer Science: 280; General Class: Science: 168, Engineering: 64, Computer Science: 332). This supported the researchers' decision to focus upon the proportions (i.e., percentages) of teacher talk rather than the counts for a more representative comparison across disciplines and between the two class sections. After data for the lessons was coded, the researchers looked within and across lessons to draw themes to compare and contrast the disciplinary-focused lessons (Miles et al., 2020).

Teacher Reflections

During implementation of the curricular unit, researchers conducted open-ended daily surveys and weekly face-to-face interviews with the teachers to collect data and insight into teachers' perceptions about their experiences with classroom enactment, including perceptions of curricular materials and classroom activities, their own characteristics, and their reasoning and views of the classroom contexts reasoning and views of the class sections (survey questions and interview protocol included in Appendix). Two researchers worked together to inductively code (Miles et al., 2020) the surveys and transcripts of the audio-recorded interviews. For first level coding, the researchers read and discussed each answer to identify if a teacher's answer demonstrated (1) teachers' beliefs about each class section or differences between the class sections and (2) how the teachers reported that their beliefs led to instructional decisions in each class section. These discussions were also used to build operational definitions for possible second level codes based on the data. For second level coding, the researchers together considered each teacher answer that received a first level code to identify statements about teachers' expectations of students' skills and prior knowledge, recognized levels of student engagement in STEM+CS activities, own prior knowledge about students, each discipline, or interdisciplinary STEM+CS, and adaptation of verbal support and classroom activities to differentiate for student ability.

The researchers then looked across coded statements to extract themes concerning teachers' beliefs about themselves, beliefs about the classroom contexts, changes they made to the project, and different ways they supported students in the different classroom contexts and wrote analytic memos (Miles et al., 2020).

Findings

In this section, we report findings for each research question to explore which SEPs the teachers verbally supported, how teachers enacted pragmatic and epistemic verbal supports between the two classroom contexts, and to report on themes emerging from teachers' rationales for their instructional decisions.

RQ1: Which SEPs did teachers support in whole-class discussions in inclusive and general class contexts, and to what extent were the supported SEPs in each class aligned with the intended SEPs suggested in curricular materials?

The SEPs that teachers supported varied between the two class sections across disciplinary lessons and sometimes differed from the focal SEPs outlined in the Teacher's Guide, within a lesson (bold, Table 1). Considering differences between the class sections within each disciplinary-focused lesson, the distribution of support across the different SEPs was similar for both class sections in the engineering and computer science lessons and varied widely between the General and Inclusive Classes in the science lesson. Considering alignment to the focal SEPs, the teachers supported a wide variety of SEPs in both class sections in the science and engineering lessons, more than those specified by the curriculum to be focal practices. The amount of focal SEP support also differed between the two classes in the science (Inclusive: 35%; General: 56%) and engineering (Inclusive: 31%; General: 39%) lessons. In contrast, 96% and 98% of the support in the computer science lesson focused on the focal practices in the Inclusive Class and General Class respectively (Table 1).

Table 1

Science and Engineering Practices Supported in Two Classes Across Three Disciplines

Science and Engineering Practices	**Science**		**Engineering**		**Computer Science**	
	Inclusive (n=177)	**General** (n=168)	**Inclusive** (n=74)	**General** (n=64)	**Inclusive** (n=280)	**General** (n=332)
Defining problems	2%	4%	53%	52%	-	-
Developing and using models	3%	6%	16%	9%	**54%**	**46%**
Planning and carrying out investigations	**15%**	**21%**	-	-	-	-
Analyzing and interpreting data	**20%**	**14%**	-	-	3%	4%
Using math & computational thinking	10%	10%	-	-	**44%**	**50%**
Constructing explanations	**-**	**19%**	-	-	-	-
Designing solutions	-	-	**15%**	**17%**	-	-
Engaging in argument from evidence	50%	26%	-	-	-	-
Obtaining, evaluating, & communicating information	-	-	**16%**	**22%**	-	-
Percentage on Focal Practices	**35%**	**56%**	**31%**	**39%**	**98%**	**96%**

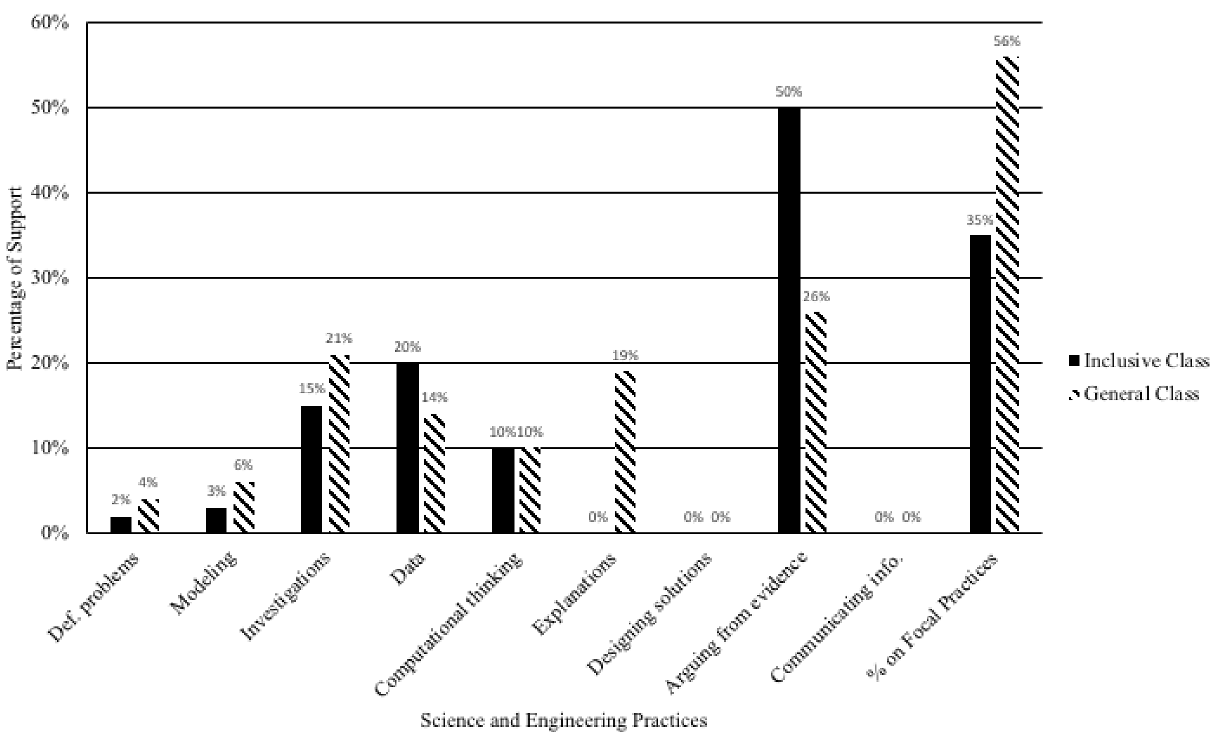
Next, we consider differences between the two class sections in support of specific SEPs within each lesson.

Science Lesson

In the science lesson, the focal practices provided in the Teacher's Guide were planning and carrying out investigations (Inclusive: 15%, General 21%), analyzing and interpreting data (Inclusive: 20%, General 14%) and constructing explanations (Inclusive: 0%; General: 19%), but the teachers also supported students to engage in defining problems (Inclusive: 2%, General 4%), developing and using models (Inclusive: 3%, General: 6%), using mathematics and computational thinking (Inclusive: 10%, General 10%), and engaging in argument from evidence (Inclusive: 50%, General: 26%; Figure 3).

Figure 3

Distribution of SEPs Verbally Supported in the Science Lesson



In the science lesson, the teachers verbally introduced SEPs beyond the focal SEPs to support students to engage in the curriculum. However, in the Inclusive Class, students received nearly twice as much support towards engaging in argument from evidence (50%) as the General Class did (26%), while not receiving any support towards the focal practice of constructing explanations, on which 19% of the support in the General Class focused. Thus, the two class sections were being supported to engage in the SEPs differently.

Engineering Lesson

Although more than half of the support in the Engineering Lesson went towards defining problems in both classes (Inclusive: 53%, General: 52%), this was not one of the curriculum's focal practices provided in the Teacher's Guide. Support towards the focal practices of designing solutions (Inclusive: 15%, General: 17%) and obtaining, evaluating, and communicating information (Inclusive:16%, General: 22%) was present, but in lower proportion. Additionally, teachers supported students towards developing and using models (Inclusive: 16%, General: 9%). Although the focal practices were supported, they did not receive the most support in implementation. In comparison to the science lesson, however, support between the two class sections was more similarly distributed across SEPs.

Computer Science Lesson

In the computer science lesson, teachers focused most of their support (Inclusive: 98%, General: 96%) on the focal practices of developing and using models (Inclusive: 54%, General: 46%) and using mathematics and computational thinking (Inclusive: 44%, General: 50%) which were included within the Teacher's guide. Analyzing and interpreting data was also supported (Inclusive: 3%, General: 4%). In comparison to the other disciplinary-focused lessons, the distribution of SEPs supported in the computer science lesson were most similar between the Inclusive and General Classes.

RQ2: What differences, if any, were there in how teachers used pragmatic and epistemic verbal supports for SEPs in whole-class discussion for inclusive and general classes?

Results show that the teachers provided different proportions of the different types of support to the two class sections (Table 2). First, we compare the two class sections across all three disciplinary-focused lessons. For both class sections, most of the teacher talk was coded as support, and most of that verbal support was *pragmatic* to support students to engage in the SEPs, with little *epistemic* or *not SEP-specific* support. The Inclusive Class also received a larger overall proportion of *pragmatic* support yet a lower proportion towards *engaging prior knowledge*. Additionally, across both classes, most of the *epistemic* support was *classroom* support rather than how the activity fit into the larger discipline (Table 2).

Table 2.

Teacher Talk Across Two Classes and Three Disciplines

Type of Verbal Support	**Science**				**Engineering**				**Computer Science**			
	Inclusive		General		Inclusive		General		Inclusive		General	
	n	%	n	%	n	%	n	%	n	%	n	%
Teacher Talk that is Curricular Support	176	90	169	72	74	70	64	78	279	77	332	79
Curricular Support that is Epistemic	13	7	20	11	16	17	3	5	15	5	14	4
Curricular Support that is Pragmatic	146	80	141	79	66	68	44	67	245	84	252	74
Curricular Support that is not SEP-Specific	24	13	18	10	16	16	19	29	32	11	75	22
Epistemic that is Disciplinary	6	50	6	33	3	18	1	25	5	31	5	33
Epistemic that is Classroom	6	50	12	67	14	82	3	75	11	69	10	67
Pragmatic that is Sensemaking	97	62	82	54	20	27	10	20	203	62	209	59
Pragmatic that is Prior Knowledge	31	20	32	21	24	32	19	38	62	19	81	23
Pragmatic that is Doing	28	18	39	26	31	41	21	42	62	19	64	18

Comparing teachers' instructional decisions across disciplinary-focused lessons, the science and computer science lessons were more similar to each other in types of verbal support than the engineering lesson. For example, in both class sections there was a lower proportion of *pragmatic* support in the engineering lesson than there was in the science or computer science lessons. Further, the engineering lesson also had a different distribution of the types of *pragmatic* support. Teachers provided more support for students to *engage prior knowledge* and perform the practices (*doing)* and spent a lower proportion of *pragmatic* support on *sensemaking* in the engineering lesson for both class sections.

There were also differences in the types of verbal support between the class sections across the disciplinary-focused lessons. For example, there was a higher proportion of *epistemic* support in the engineering lesson for the Inclusive Class (Engineering: 17%) than for the General Class (Engineering: 5%). Below, we further examine differences between types of support for the two class sections within each disciplinary-focused lesson.

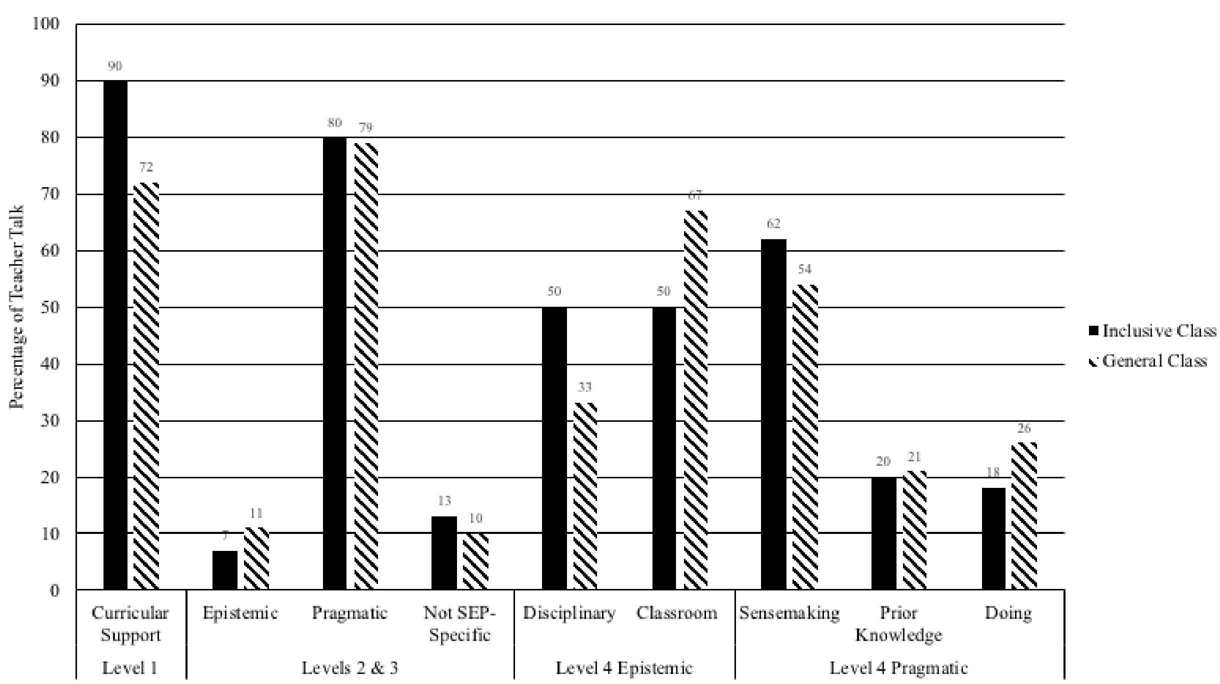
Science

In the science lesson, the overall percentage of *epistemic* support provided through teachers' instructional decisions is low compared to the amount of *pragmatic* support, and there was a notable difference between the two class sections between *disciplinary* support (Inclusive: 50%, General: 33%) and *classroom* support (Inclusive: 50%, General: 67%; Figure 4). Because there were so few instances of *epistemic* support in comparison to *pragmatic* support, a single additional instance of *epistemic* support had a noticeable effect on differences in the proportion of *disciplinary* and *classroom*.

For *pragmatic* support, a difference in the verbal support in the two class sections, shown through the greater proportion of *sensemaking* support for the Inclusive Class (Inclusive: 62%, General: 54%) and *doing* support for the General Class (Inclusive: 18%, General: 26%; Figure 4). In the Inclusive Class, teachers made the instructional decisions to lead students to do science activities together and supported students to sensemake as a class in whole group discussion. In the General Class, teachers made the instructional decision to offer students the opportunity to try science activities in pairs or individually and, to prepare students, supported students by giving them instructions (*doing*). These instructions could help students to do an activity or prompt them to discuss ideas with their partners, which in turn enabled students to sensemake with each other, rather than through whole-class discussion.

Figure 4

Distribution of Teacher Talk in Science Lesson across Two Class Sections



Even when the teachers structured activities in similar ways, the type of SEP support was not consistent between the two classes. For example, teachers introduced making predictions to the whole class in both classes, and then sent students to work independently. When verbally supporting the General Class to make predictions, Ms. Banet made an instructional decision to use statements to support *prior knowledge, sensemaking*, and *doing* that helped students to recall prior knowledge regarding design constraints, encouraged them to use their prior knowledge of different surface materials, provided sensemaking information about what a prediction is, and gave instructions for how to create their prediction:

> So today we're actually going to explore that a little further, about what happens when water hits different surfaces. We decided that your engineering design was going to withstand one inch of rainfall per hour. Your answer is just going to be a prediction, I believe grass will do what with water when water hits it. Don't forget the why part to your predictions, the part that says because. So you're using any prior knowledge you have about grass or concrete to explain your claim or prediction that you're making.

In the Inclusive Class, Ms. Banet made the instructional decision to provide only *doing* support for making predictions by telling students, “Go ahead and pull up 4.1. Give me a thumbs up when you’ve made a prediction about what will happen when rainfall hits grass and when it hits concrete.” Thus, in this example, the Inclusive Class received less comprehensive support regarding how to make predictions and engage in the activity.

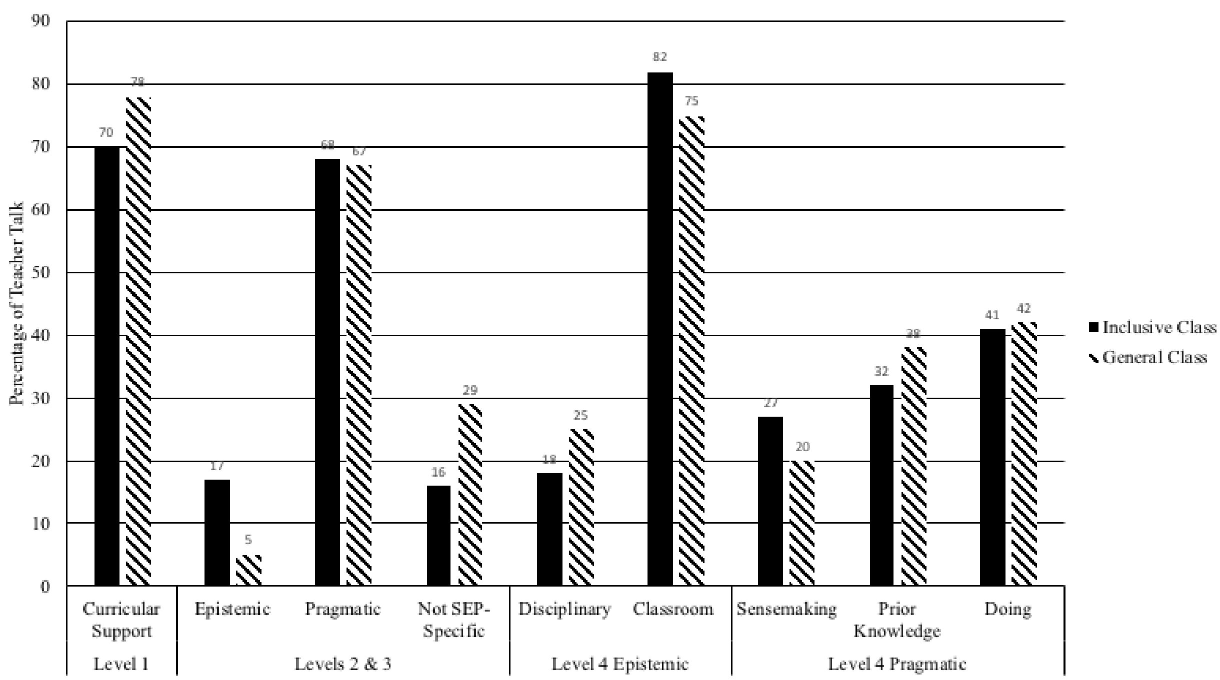
Further, the structure of these whole-class discussions was different in student input. As an example, in the General Class, Mr. Skelton and Ms. Banet led students in a whole-class discussion of questions that supported students in *sensemaking*, provided opportunities for students to add to and expand upon the contributions of their peers, and enabled students to work together to define the concepts of permeability and impermeability. The teachers then continued to support students to share their own examples of impermeable surfaces. In contrast, in the same whole-class discussion for the Inclusive Class, Ms. Banet defined permeability for the students and did not elicit examples from the class. Further, the concept of impermeability was not discussed. Instead, Ms. Banet had students repeat the terms aloud as a group.

Engineering

Whole-class discussions differed between the class sections in the engineering lesson as well. In the Inclusive Class, teachers provided lengthy teacher turns of talk uninterrupted by student input. In contrast, teachers in the General Class elicited more student input throughout the whole group discussion. The higher proportion of *not practice-based* support in the General Class (Inclusive: 16%, General: 29%; Figure 5) may seem to indicate that the teachers focused less on engaging students in the SEPs. But this *not practice-based* support was actually instances of the teacher eliciting student participation in the whole group discussion by saying things such as “any other questions about this?” and “what else?”

Figure 5

Distribution of Teacher Talk in Engineering Lesson across Two Class Sections



There were also differences in the distribution of whole class discussions between the class sections. In the Inclusive Class, the teachers stated detailed instructions to the entire class to front-load support through whole-class discussion before students began to work on their own. For example, at the start of an activity in the engineering lesson, Mr. Skelton said:

> On average our hourly rainfall at [school] is 13 hundredths, so I think you guys tried to find somewhere in the middle for a heavy rainstorm. Okay, so we're going to set our hourly rainfall to 0.50 because I'm almost positive that's exactly what you guys voted on earlier. And then we can figure out a rain duration in just a minute. And then you guys are going to test your designs, but here's how it's going to work.

Here, Mr. Skelton did not offer an opportunity for the students to discuss the hourly rainfall decision, or to reason about their decision beyond the idea that they voted on it the other day. He then continued with very explicit instructions about the students’ tasks for the rest of the activity.

The General Class, in contrast, was often sent to try the activities independently, with teachers providing whole-class help as questions arose. For the same activity as the example in the Inclusive Class, Mr. Skelton gave the General Class the following instructions:

> Well today you guys are going to get a chance to test a working model, but before you test your design, turn to page 26. You are going to create two more designs based on this same criteria, with perhaps different surface materials. Or a different set up, however you want. So you have to create two more designs and then we're actually going to test all three and see how they compare to each other.

The teachers gave the General Class time to attempt the task on their own, and then they addressed questions with the whole class as they arose. For example, in the same activity, Ms. Banet interrupted students’ individual work time for a whole-class discussion, saying:

> As you are testing your designs, some of you might be running into an issue where you're getting negative runoff. If you're getting negative runoff, that's because you need to reset where you test. So, down at the bottom, bottom of the code, So way below the absorption ratios for different materials, it says… there's a reset button here. If you press resets, it resets your uh rain gauges at the bottom. Any other questions?

Additionally, while most of the *epistemic* support offered in both classes was for *classroom context* rather than for *disciplinary* thinking, teachers offered a larger proportion of *epistemic* support in the Inclusive Class than there was in the General Class (Inclusive: 17%, General, 5%; Figure 5). The teachers carefully framed the engineering activities for the Inclusive Class each day, while relying on the students' ability in the General Class to recall the framing from previous days. For example, Mr. Skelton introduces an activity in the Inclusive Class by saying "I just wanted to orient you to what we're doing today" and then proceeding to recount unit context from the previous day. For that same activity, Mr. Skelton started the General Class by saying "All right, so ladies and gentlemen, we're going to pick up exactly where we left off" and quickly moved into *pragmatically* supporting students to engage in the activity, giving the General Class less *epistemic* support and also more time to engage in the activity.

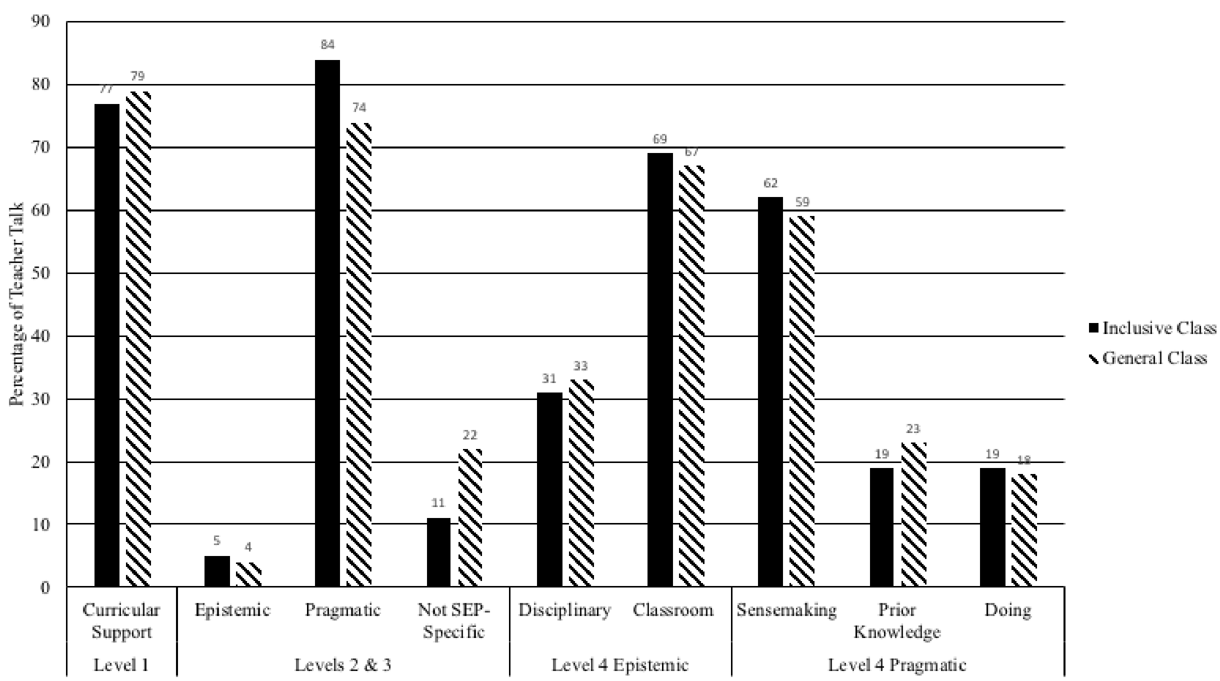
There were also differences in the ways that the teachers supported students to share their results in the engineering lesson. Ms. Banet supported the general class to understand what kinds of information are useful in a presentation through *pragmatic, doing* support. The support was in such a form that when making presentations in the future, those students may be able to apply some of these ideas. The Inclusive Class, in contrast, received only *doing* support towards sharing their results in a different format, where the steps were broken into smaller chunks and the support was focused on how to create this presentation, rather than how to make an informative presentation broadly or why to include certain information. The teacher supported them to do the immediate task, but not in a way that was transferable to future presentations they might give, and the teachers did not try to engage the students' prior knowledge as frequently as they did in the General Class (Table 2). While the two classes received similar proportions of *doing* support in the engineering lesson (Figure 5), that support was carried out in different ways; thus, students in the two classes were not having the same experiences.

Computer Science

With a majority of the teacher talk focused on focal practices (Inclusive: 98%, General: 96%; Table 2), support in the computer science lesson was most aligned both to the Teacher's Guide and between the two class sections (Figure 6).

Figure 6

Distribution of Teacher Talk in Computer Science Lesson across Two Class Sections



For example, the distribution of teacher talk that supported students to engage epistemically through *disciplinary* and *classroom* support and pragmatically through *sensemaking*, *prior knowledge*, and *doing* was similar between the two classes (Figure 6).

However, the structure and content of teachers' verbal support to help students engage in activities was different between the two class sections, despite their similar proportions.

Often, teachers led the Inclusive Class through the computational activities by giving direct instruction through whole-class discussion while allowing students in the General Class more opportunities to work with partners to engage in computational activities on their own, outside of whole class discussions. For example, when creating the mathematical models in the computer science lesson, the teachers let students in the General Class try to create their own models and led students in the Inclusive Class to create the model together. So in the General Class, the teachers first verbally supported students to find patterns and create variables from data tables, led them through whole-class discussion to create a mathematical model for runoff, and then instructed students to try themselves to create a mathematical model of total absorption with a student partner. This structure supported students to learn how to create mathematical models by modeling the process, supporting them to transfer their understanding to a new situation, and encouraging them to engage in the process on their own. Further, Mr. Skelton supported students to understand why they were creating mathematical models, telling them, "If a computer's going to understand what total absorption means, we have to put our understanding of this into mathematical terms." Through this process, students in the General Class learned how to engage in mathematical modeling in a way that they might then be able to transfer to other science, engineering, or computer science contexts in the future.

In the Inclusive Class, the teachers made instructional decisions that focused on making sure that students understood mathematical models that were created together through whole-class discussion rather than helping them develop the ability to create their own models.

So instead of referring students back to tables or verbally supporting them to find patterns and develop models as an example for future practice, for each model the teachers moved directly to considering how the variables included in the model were related without giving students the opportunity to discuss with a partner or think through it on their own.

The teachers also supported the students to understand the mathematics of the models they were creating differently between the two class sections. Specifically, while creating a mathematical model as a whole class in the Inclusive Class, Mr. Skelton provided support but changed a student's response of the specific operation used in the model from addition to multiplication without providing support for why this change could, or should, occur. In contrast, during a whole-class discussion in which students shared and compared the mathematical models that they created in the General Class, Mr. Skelton helped students to understand the connection between additive and multiplicative properties by considering two different student mathematical models. He provided *disciplinary epistemic* support, saying "So you could have done it either way, which is a really important point when you're coding. There's not always one solution. There's often lots of different solutions. So if you've got here a different way, that's wonderful." This support, both to understand the connection between additive and multiplicative properties as well as to consider the disciplinary idea that there is not necessarily a correct answer but rather multiple solutions in computer science, was possible because the teachers enabled students to create their own mathematical models and produce various answers rather than leading them to a single model through a whole-class discussion.

Creating Computational Models. Differences also included how teachers supported students to create and debug their computational models. For example, in the General Class, the teachers had students attempt to create code with partners or individually and then asked for volunteers to present their coding to the whole class. Through whole-class discussion, teachers supported students to compare their code and trouble-shoot specific aspects of the code together:

> Ms. Banet: So we're trying to figure out how did you calculate total absorption here? So, you put it as a starting variable. How did you calculate it here? What did you manipulate? What code did you put in here?
> Mr. Skelton: Maybe you should see if your code looks like theirs, or if yours looks different. So just take a minute to see how yours compares.

The teachers continued to support students to explore their computational model to try to figure out how to do it themselves, as Mr. Skelton said,

> I'm going to let you guys fish around with this for a little bit and try it on your own to try to figure out a way to include this formula in our repeat until block and see if you get something for absorption.

This opportunity to experiment with their computational model resulted in one student figuring out a way to duplicate his code instead of rewriting the code for different variables. Mr. Skelton then offered the student the opportunity to share his findings with the class, thus privileging the student's ideas.

In the Inclusive Class, the students did not have the same verbal support to develop or share their own examples of codes or ideas with their classmates. Instead, the teachers used whole class discussion to support students to replicate code that the teachers presented:

> Ms. Banet: So the model that is supposed to be the working model is actually incomplete, so you guys are gonna have to follow along up here with adding in the set blocks.
> Mr. Skelton: Just the set block is right up here to the left, drag two of them over, and then drag in the variables. Sometimes it's hard to drag them into the left hand side.
> Student: Can you slow down a little bit?
> Mr. Skelton: I'll give you a minute so everyone can catch up.

Because students continued to struggle to replicate the code that they were shown, the teachers then made a decision to provide students in the Inclusive Class with a completed computational model, rather than trying to have them create or copy it from the board.

RQ3: What kinds of rationales did elementary teachers report for making instructional decisions within inclusive and general class contexts?

Modifying Support for Inclusive Contexts

The teachers' responses to the surveys and interviews reflected on modifying support for students based on their noticing of when students were having difficulties in engaging in specific activities and anticipating the need for different supports for students in the Inclusive Class than students in the General Class. To focus on modifying their instructional support for the Inclusive Class, teachers reflected on the ways that they tested activities out in the General Class and then modified them for the Inclusive Class. According to the teachers, these modifications took the form of skipping questions that they would have asked in whole-class discussion, truncating or removing verbal support of specific activities, and adding verbal support to lead students through other activities in whole-class discussion rather than having students complete activities individually as suggested in the Teacher's Guide. For example, Ms. Banet reflected, "A couple of the slides I didn't think kids would understand. So we cut those slides." Mr. Skelton wrote in his survey that, after noticing that some students in the General Class had difficulties with adding initial values and change rules to their models, the teachers reported making changes for enactment with the Inclusive Class, saying:

> We used direct instruction more than suggested with [the Inclusive Class], leading them through the initial values and change rules and we guided students in [the Inclusive Class] through the engineering design more so than the lesson suggested.

Additionally, as demonstrated in the findings above, the teachers gave different opportunities to students in the two class contexts in enacting the science lesson. Specifically, in the General Class, the teachers offered students the opportunity to understand the design of the experiment before carrying it out, and, in the Inclusive Class, the teachers supported students by modeling the experiment for them and then allowing them to copy the procedures that they had seen. Reflecting on this activity, Ms. Banet said,

> We kind of lead [the Inclusive Class] through it. Like piece by piece, instead of letting them just design it, because they were struggling to figure out what to do after that stage. I think part of it is written instructions or the inability to read the instructions themselves.

These differences in support also led to the teachers recognizing differences in the students' successes in the project. For example, Mr. Skelton wrote that the Inclusive Class was "successful in carrying out the first experiment after watching me do it" but the General Class was "successful in designing the experiment and carrying out the modeled experiment."

The teachers also reported cases in which they made changes to the science lesson to support student learning in the Inclusive Class despite feeling that the lesson was successfully enacted in the General Class. For example, Ms. Banet stated in her interview regarding the General Class, "I think that [General Class] was successful in understanding the difference between permeable and impermeable and also understanding the absorption ratios." But then, anticipating student needs, the teachers made instructional decisions to add supports to help students reach specific ideas in the Inclusive Class, such as creating charts that the teachers filled in during whole-class discussions. Ms. Banet reflected on these specific changes, saying:

> I actually think it worked against the kids [in the Inclusive Class] and kind of limited their discussion. Because once some students shared then the other ones are kind of like shutting down and just writing what was on the board. I don't think that was a very good instructional decision.

Thus, Ms. Banet believed that this way of trying to support students may have changed opportunities for students in the Inclusive Class.

The teachers also discussed making other substantial changes to their verbal support for the Inclusive Class in the computer science lesson. Originally, students were supposed to create their own computer code to test their designs. Instead, after noticing challenges in facilitating the activity in the General Class, the teachers tried to support the Inclusive Class by verbally leading them step-by-step through the coding in a whole-class discussion. Even with this additional verbal support, the teachers felt that the Inclusive Class struggled to understand how to code and were running out of time. Mr. Skelton explained, “I felt the class wasn't making enough progress,” and the teachers made the decision to move more quickly through activities in the computer science lesson. So, the teachers verbally gave students in the Inclusive Class the final computer code to use so that they did not have to create it for themselves. Thus, the teachers made changes to their verbal support based on their perceptions of how to support student understanding and to save time which led to different experiences for students in each class section. Ms. Banet said that she believed that the Inclusive Class was “short changed” by these modifications.

Still, the teachers reported positive outcomes from this instructional decision to change the support that students received for creating computer code. For example, Ms. Banet reflected, “Providing them with the working model alleviated a lot of stress.” The teachers also reported ways that they believed they could better support students in inclusive classroom contexts to engage in computer coding in the future. For example, Ms. Banet stated that,

> I think that it goes back to perhaps the vocabulary and then us not doing enough of talking about the variables inside the code and how we have to change them and why we have to change them. I think if they had a better understanding of the vocabulary and the variables it would have been easier for them to change them on their own.

Thus, she believed that she could better support students in the Inclusive Class to modify and create computer code if she first helped them to understand the computational thinking concepts and purposes underlying computer coding.

Teachers' Reported Challenges in Inclusive Contexts

Teachers also reflected on their own challenges to implement this project in an inclusive setting. For example, the teachers reported struggling to facilitate whole-class discussion either student-to-teacher or student-to-student in the Inclusive Class. Teachers reported that these difficulties may have led to a majority of teacher talk in the whole-class discussions in the Inclusive Class. The teachers recognized possible ways to better support students in the Inclusive Class in future iterations so that students could more frequently contribute their ideas within whole-class discussion. For example, Ms. Banet reflected that teachers could encourage student talk outside of this project so that, in her words, there is "more of a buildup throughout the year".

Teachers reported feeling pressure to move quickly through these activities and catch up to the curriculum pacing, particularly when discussing the Inclusive Class. For example, Mr. Skelton reported, "We did far more direct instruction and much less independent work [in the Inclusive Class] as the pace of our teaching had to increase" and "we also skipped over the remainder of the activity with [the Inclusive Class] for the sake of time." This pressure may have led to the difference in the ways that students in the Inclusive Class were supported to engage in activities.

Teachers' Suggestions for Additional Support

Throughout the interviews and surveys, the teachers reported that they struggled to differentiate this interdisciplinary project for students with different needs and suggested additional support that they felt would be helpful for enacting this project. For example, Ms. Banet reflected on the science lesson saying, "I could use more help in scaffolding for students." Similarly, when reflecting on the computer science lesson, Mr. Skelton stated "differentiating for ability level was a struggle for me" and suggested that he could have used additional professional development to prepare for "differentiating this for varied learners." Thus, the teachers felt that they needed more help through additional professional development in order to be able to offer verbal support that would help all students to engage in the SEPs as intended by the Teacher's Guide and to provide equitable STEM+CS experiences for all of their students.

The teachers reported struggling to help students in both classes troubleshoot code. Ms. Banet reflected that these difficulties may have decreased their ability to support students, saying:

> There were a couple of times where the students' programs were malfunctioning, and I didn't know how to help other than having them close out their program and bring up a whole new copy. A couple of girls, they didn't know why it wasn't running the program ... and they ended up having to start over because I didn't know what else to do.

These reported feelings of struggling to support students in troubleshooting code for computational models may have led to differences in how students were supported to create computer code in the two class sections. Due to difficulties implementing the computer modeling content, the teachers reflected on wanting to condense the computer science lesson to help reduce what they anticipated as potentially challenging for students. Ms. Banet said, "I think I would condense the coding part a little bit. Instead of having them code for six variables, figuring out a way to only have them code four variables. Just reducing the amount that they have to understand." Thus teachers suggested additional supported based on the challenges that they recognized in providing differentiated verbal support when enacting the interdisciplinary curricular materials in the two different class contexts.

Discussion and Implications

The NGSS were designed to support teachers to facilitate authentic STEM+CS experiences through student engagement in SEPs (NGSS Lead States, 2013). In addition to providing support to enable authentic engagement for all students across disciplinary-focused lessons, interdisciplinary STEM+CS experiences also need to be made available to students with disabilities by implementing NGSS-aligned curricular activities within inclusive classroom contexts. The teachers in this study engaged in the challenging work of implementing an NGSS-aligned unit by adapting the curriculum materials based on their knowledge of their students' needs, including verbally supporting students across different class contexts and supplementing the materials with additional activities (Lilly et al., 2021).

While we expected there to be differences in the way the interdisciplinary project was enacted in the inclusive classroom context, as teachers use their knowledge of students to support student needs, the differences we observed may have led to inequitable experiences for the students in the two classes such that the Inclusive Class may not have had as many opportunities to engage in the curriculum as intended. It is important to recognize the differences in the types and kinds of verbal support to engage in SEPs that were available to students based on their placement in a general or inclusive class, particularly in this unique case where the teachers had degrees in a science field and NGSS-aligned curriculum materials. An implication is the need for

NGSS-aligned curricular materials specifically tailored for inclusive settings (i.e., responsive engineering teaching; Wendell et al., 2016).

Interdisciplinary Curricular Materials: Teacher's Guide

Teachers' perceptions and understanding of interdisciplinary pedagogical strategies included in the curricular materials may have affected the decisions that they made about how to organize and represent content as well as how to implement instructional strategies in whole-class discussions in each lesson (Gess-Newsome, 2015). Specifically, we infer that when teachers were in line with the SEPs planned in the Teacher's Guide when implementing this interdisciplinary unit, then they were drawing on interdisciplinary pedagogical strategies offered by the Teacher's Guide. Our results add nuance to prior understandings of pedagogical strategies in curricular materials as a link between teachers' understanding and prior experiences with national frameworks and practice by showing that, in interdisciplinary contexts, teachers' use of pedagogical strategies in curricular materials may change based on their prior experiences and knowledge of different disciplines.

First, teachers may rely on the interdisciplinary pedagogical strategies provided in the Teacher's Guide when they do not have knowledge or experience in a discipline from a framework or prior experiences to draw upon. For example, throughout the computer science lesson, teachers may have been less able to pull upon prior experiences within computer science or the other disciplines to recognize students' needs or able or willing to provide verbal support of additional SEPs. Instead, the teachers made instructional decisions to more closely adhere to the focal SEPs and other forms of interdisciplinary pedagogical strategies suggested in the

Teacher's Guide and provided similar verbal support in alignment with the focal SEPs between the two classroom sections.

However, when teachers have experience or knowledge in the discipline to draw upon, then the teachers may not rely on or utilize interdisciplinary pedagogical strategies and instead draw upon their own knowledge and prior understanding of disciplinary strategies. For example, in this study, we note that the teachers had a background in science from science degrees and prior science teaching experience. Our results indicate that these teachers may have then been more able to recognize students' needs in science as well as more comfortable verbally supporting additional SEPs in the science lesson through verbal support that was not included in the provided interdisciplinary curricular materials. This differentiated verbal support then led to different experiences for students in the two class contexts.

We acknowledge that a teacher's understanding of and prior experiences in a discipline may not always have the same effect on their use of the interdisciplinary pedagogical strategies suggested by the curricular materials to support students. For example, our results also show that *disciplinary* support occurred in a larger proportion in the science lesson, specifically for the Inclusive Class whom the teachers perceived as requiring more support to be engaged. Here, the teachers had understandings about the broader discipline of science and then were either more able or willing to access the suggestions and strategies in the Teacher's Guide to make epistemic connections to the discipline of science clear for these students. This led to students in the Inclusive Class receiving different support to engage in science than in engineering or computer science. Further, students in the General Class may have benefited from this epistemic support as well.

Our findings highlight how, in interdisciplinary units, the ways that teachers choose to utilize the curricular materials for each discipline may affect instructional decisions about the implementation of verbal supports across disciplinary-focused lessons. An implication from these findings is that teachers may need educative materials and professional learning opportunities in order to support their knowledge of and facility with interdisciplinary pedagogical strategies and practices, and how those strategies and practices relate to those needed to support individual disciplines. Thus, an implication for curriculum designers is that they may need to incorporate additional support within curricular materials as well as help teachers to engage with these supports across familiar and unfamiliar disciplines to integrate new knowledge and utilize curricular materials. Additionally, curriculum designers may need to provide personalized professional development opportunities that build from the strengths that teachers are bringing to their instruction and also to help each teacher to develop an understanding of epistemologies across disciplines as well as an ability to connect classroom activities to the authentic practices of the disciplines.

Teacher Characteristics and Classroom Enactment

Teachers' perceptions of student needs can affect how teachers make instructional decisions to support students in specific classroom contexts (Gess-Newsome, 2015). This was reflected in our results for an interdisciplinary context, as the teachers' decisions were demonstrated through their verbal support and reflections and may have contributed to different learning experiences and opportunities for students across disciplines based on their class section. For example, students in the General Class were exposed to learning opportunities regarding reasoning skills that could be applied to other situations based on their meaningful contributions in whole-class discussion. In trying to modify their support to meet student needs, whole-class discussions in the Inclusive Class became more teacher-led. Teachers then recognized ways that they need support in future implementations to meet their students' needs while still ensuring every student's deep understanding of the SEPs (Windschitl et al., 2018).

Teachers enacted SEPs in the computer science lesson in alignment with the intended curriculum and with similar verbal supports between the two class sections, which may have been a result of their being less familiar with computer science. An implication is the importance of teachers having computer science-specific pedagogical content knowledge to be able to then help students engage in computational thinking-based SEPs in the classroom. Although teachers may have practice facilitating students' sensemaking in science-focused SEPs, these strategies and supports may not translate to computational thinking-focused SEPs. Thus, teachers may need support to develop similar pedagogical practices and skills across SEPs that integrate science, engineering, and computer science (Cunningham & Carlsen, 2014; Dasgupta et al., 2017).

However, the ways in which teachers verbally structured student engagement with these SEPs was different between the two class sections. This difference may have occurred as the teachers felt pressure to regain time in the computer science lesson coupled with less experience in the discipline of computer science. Teachers reported that these feelings led them to make instructional decisions, such as cutting activities suggested by the Teacher's Guide or giving students code for their computational model, that inadvertently reduced opportunities for students in the Inclusive Class to engage in computer science practice. For example, students in the Inclusive Class were not supported to try to create a mathematical model of runoff on their own. Further, teachers positioned students as knowledge creators in the General Class by giving them verbal support and structuring the class to allow for students to work on their own or in partnerships and then share their knowledge by presenting their code or ideas to their peers. Positioning students in this way and comparing student work led to discussions that exposed students to the possibility of having different solutions in computer science. This was different in the Inclusive Class, where teachers led students' understanding by having students replicate what the teachers had done with, often, a single solution.

The teachers verbally supported students in the Inclusive Class with a larger proportion of pragmatic support across all three lessons. This instructional decision may have come from the teachers' knowledge of instructional practices in SPED around verbal support in the form of providing direct instruction to students (Therrien et al., 2017) when teachers notice that students struggle with an activity or concept. Students may have also received more overall sensemaking support in the Inclusive Class but not the same support to engage in the experience on their own particularly when we compare specific activities between the two class sections. For example, teachers tended to be focused on leading students to knowledge in the Inclusive Class by doing much of the talking in whole-class discussions instead of eliciting student ideas or making student thinking visible to collectively work on one another's ideas (Windschitl et al., 2018). This may have led to teachers asking for more student input in the General Class than in the Inclusive Class. Further, in the science lesson, teachers focused on verbally supporting common science knowledge in the Inclusive Class and curriculum-specific information in the General Class. This may have stemmed from teachers noticing ways to modify their verbal support to help students in the Inclusive Class to engage in this challenging NGSS-aligned unit.

General education teachers may need additional support to meet students' individual needs (Librea-Carden et al., 2021) without limiting students' opportunities to engage in the curricular activities or with authentic NGSS practices. Such support could help teachers to maintain a student-centered, rather than teacher-centered, learning environment. This shift in instructional practice requires specific strategies, practice, and support as a priority within the instructional context. Additionally, SPED teachers may need additional support to help students engage in science and specifically in NGSS-aligned curricula (Taylor & Villanueva, 2017) and to collaborate in implementing NGSS-aligned curricula with the general education teachers.

Teacher Reflections

Unrelated to this curricular unit, students in this study were placed in different classrooms based on their previous achievement in mathematics and/or additional support needed through an IEP. As indicated in the interviews and surveys, this tracking of students may have impacted teachers' perceptions of students, including instructional decisions regarding how to provide different support to help students to engage in the SEPs in different classroom contexts. These differences in teachers' verbal support, based on teachers' prior perceptions and modifications to support students with individualized needs, may have unintentionally created a different experience with the curricular activities for students in the Inclusive Class than was intended by the Teacher's Guide.

Specifically, our findings show that, although students with disabilities are shown to be capable of engaging in SEPs (Therrian et al., 2017), the Inclusive Class may not have had as many opportunities to engage in the curriculum as intended. For example, in the Inclusive Class, there was generally a lower proportion of *pragmatic* support toward *engaging prior knowledge* than there was in the General Class. Similarly, giving the Inclusive Class the code and showing them how to add models, rather than having students explore the technology, exemplifies how students in this specific class context were afforded less opportunity to engage in the curriculum on their own than the General Class. Teachers reported how such instructional decisions to modify activities and offer different verbal support in the Inclusive Class resulted in a less student-focused implementation of the interdisciplinary STEM+CS project than suggested by the Teacher's Guide. However, these different verbal supports and modifications to the interdisciplinary curricular materials may have been necessary for some students to engage in the curriculum at any level. Thus, future research should consider the ways in which to support teachers to meet the needs of their students in accessing and engaging in interdisciplinary STEM+CS in ways that still align with the intended goals of the curricular materials.

Our findings also show that the academic backgrounds of the students in the two classroom contexts, specifically whether they took advanced or grade-level mathematics, created challenges for the teachers in how to differentiate activities while still providing equitable opportunities for students to engage in the project. Although in integrated curricula the specific mathematics concepts being integrated should be closely considered for alignment to content as well as students' level of understanding (Lilly, Fick, et al., 2020), curriculum makers may need to consider ways to differentiate activities such that teachers can support all students to engage in a curricular unit regardless of prior mathematics achievement and to ensure that mathematics is not a gatekeeper to authentic engagement with SEPs. Factors of previous mathematics achievement or disability do not necessarily mediate the level to which a student can engage in interdisciplinary STEM+CS and should not influence the learning opportunities in integrated science, engineering, or computer science that are provided to students. For example, a student who struggles with early mathematics may flourish in creating an engineering solution or design if given the opportunity and support to engage in SEPs.

An implication of these results is that teachers may need additional support with less familiar disciplinary practices to be able to meet the needs of their students while still helping students to engage in authentic practices of the curricular project and feel comfortable using additional SEPs to engage students in the curriculum activities. Additionally, in the context of teacher education, preservice teachers may need opportunities to engage in NGSS-aligned activities that are focused on different disciplines themselves as well as to practice implementing NGSS-aligned curricula with support from mentors and coaches.

Limitations and Future Research

This research primarily focused on examining transcripts of whole-class discussion with two teachers in two classroom contexts which might have limited our ability to observe other supports that the teachers were providing to students. Additionally, data collection and analysis did not consider what might have occurred in small group or one-on-one discussions, or whether the supports were related to increases in student learning. Findings from the whole-class discussion showed that teachers necessarily adjust and customize curricular materials to specific learning contexts, and also highlighted the potential of unintended outcomes that may arise as a result of customization as students in different class sections received different kinds of verbal support that may or may not have a positive impact on students. For example, providing additional verbal support for students in the Inclusive Class may have affected the intended engagement in SEPs through the activities or caused whole-class discussions to become more teacher-centered.

However, these adaptations to the NGSS-aligned unit, although often seemingly restrictive to students' opportunities to authentically engage in disciplinary practices as were intended by the Teacher's Guide, may have afforded certain students more access to engage in specific practices than would have been possible without the additional support. Additional investigation of student learning outcomes is then necessary to consider if the ways in which teachers chose to adapt verbal supports is beneficial to different students in different disciplines.

Further, other strategies and instructional decisions that teachers made in the Inclusive Class may be necessary for students with disabilities but also beneficial to all students. Future research into supports that are necessary for some but helpful for all students in interdisciplinary contexts could help curriculum developers and teachers to create standard strategies that should be enacted across classroom contexts. Subsequently, professional development could likely be important to help teachers feel comfortable adapting curricula for familiar and less familiar disciplines in ways that help students to both access and authentically engage in disciplinary practices.

In addition, future work should explore how teachers' support in small group and one-on-one discussions may relate to students' learning experiences to help teachers to still provide support based on students' needs but also maintain equitable learning opportunities for all students. Future research should also consider how teachers with different domain experience support students during implementation of NGSS-aligned curricular projects.

Findings also highlight the need for further research into the kinds of interdisciplinary instructional moves that teachers may add to instruction to provide crucial insight into revisions of educative materials and enactment of NGSS-aligned, interdisciplinary units. Specifically, given the importance of helping students to understand the nature of science, engineering, and computer science disciplines and how they fit together, future research can also investigate how to support teachers to provide disciplinary epistemic support for SEPs that integrate disciplines (e.g., K-12 Computer Science Framework, 2016).

We note that comparing differences in types of verbal support in each disciplinary-focused lesson may not be as important as understanding the overall distribution of verbal support across an NGSS-aligned unit. Further, all types of support for all disciplines may not necessarily have to occur in one unit; rather it is important that teachers provide types of verbal support for different disciplines that build throughout and across units such that students have access to the support to pragmatically and epistemically engage in disciplinary practices throughout their engagement in NGSS-aligned units. Still it is important to consider teachers' instructional decisions, and the ways that teachers' beliefs filter their instructional decisions, in implementing verbal support within each lesson of a unit in order to begin to build an understanding of the experiences and opportunities that students are being afforded as well as the help that teachers may still need to provide students with opportunities to engage in authentic STEM+CS practices within and across NGSS-aligned units.

Conclusions

This paper highlights examples of how teachers verbally supported students to engage in an NGSS-aligned unit in two different class sections. Results show how classroom context can influence the kinds of verbal supports that teachers may choose to enact to support specific student needs. For example, teachers made changes to ways in which they verbally supported students based on their own knowledge of the different disciplines being integrated, their prior beliefs of students' abilities to engage in SEPs and about different classroom contexts, and their perceptions of student understanding content or progress through activities. These changes led to different learning experiences for the students in each classroom context. For example, teachers provided students in the Inclusive Class with the same code in the computer science lesson as a class rather than supported them to create their own individually or in small groups. This focus on conformity rather than creativity could affect the students' global epistemological understandings of the science, engineering, and computer science disciplines. Findings also suggest that teachers may need additional support to understand and epistemically situate engineering design and computational thinking to disciplinary and real world contexts rather than just the context of the project for all students.

This study puts forth a need for additional research to better understand what kinds of support teachers need to be able to integrate STEM+CS and practices within their elementary classrooms and provide equitable learning opportunities for all students across disciplines. Further, this study underscores the importance of providing comprehensive curriculum materials, educative supports, and professional development for teachers to help them gain knowledge and familiarity of the SEPs and epistemologies of disciplines. Providing these supports for teachers who are doing the challenging work of implementing NGSS-aligned curricula is thus important toward ensuring equitable learning opportunities for all students, particularly those in inclusive classroom contexts, across science, engineering, and computer science.

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Appendix

Codebook

Level 1	Level 2	Level 3	Definition	Examples
Curricular Support	SEP-Epistemic	Disciplinary	Explicitly explains how practices fit within the larger discipline	*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* - Mr. Skelton, Engineering
		Classroom	Explicitly explains how an activity fits into the larger unit or orients students to the unit	*Keep that thought in mind for when we move onto the actual design and we get to test different surfaces cause what you're talking about you're going to get to actually play around with and see how different surfaces react to different amounts of rainfall.* -Ms. Banet, Science
	SEP-Pragmatic	Sensemaking	Supports students to make sense of new information or build new understandings	*So did the water actually pass through the soil? What do you guys think?* - Ms. Banet, Science
		Engaging Prior Knowledge	Supports students to draw upon information they had already learned	*Our buildings, as you guys pointed out, do have accessible to wheelchairs, but it takes a really long time to get from one place to another.* - Mr. Skelton, Engineering
		Doing	Models how to do a particular practice, generally in the form of instructions or a demonstration	*So you're taking your claim and your evidence and you're combining them to create your reasoning.* - Ms. Banet, Science
	Not SEP-Specific		Supports students but not towards a specific practice	*So go to google classroom and click on the link.* -Mr. Skelton, Computer Science
Classroom Management			Focuses on facilitating movement in the classroom, calling on students, or managing behavior	*Everyone should be on page 7 and you're answering these two questions at the bottom of page 7. You have a minute and 30 seconds.* - Mr. Skelton, Science

Daily Survey and Interview Questions

(1) What do you feel like students were successful with today?
(2) What do you feel like students struggled with today?
(3) What did you feel confident about in your teaching today?
(4) What did you struggle with in your teaching today?
(5) What changes did you make to today's lesson to support students' learning?
(6) Was there anything that came up in today's lesson that you felt like you could have used some additional Professional Development to prepare for?

A Case Study of Elementary Teachers' Classroom Enactment of an NGSS-Aligned STEM+CS Project: Verbal Support of Interdisciplinary Integration

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Abstract

National frameworks for science education in the United States (e.g., American Society for Engineering Education (ASEE), 2020; *Framework for K-12 Science Education;* National Research Council, 2012) have worked to bring science, technology, engineering, mathematics, and computer science (STEM+CS) disciplines together through curricula in K-12 classrooms (ASEE, 2020; Computer Science Framework, 2016; NGSS Lead States, 2013). This study describes how two fifth-grade teachers verbally supported elementary student engagement in a NGSS-aligned project that integrated science, engineering, mathematics, and computer science within two disciplinary-focused lessons (i.e., science lesson and computer science lesson) and considers teachers' perceptions through survey and interview data. Transcripts of whole-class discussion were analyzed for instances of interdisciplinary integration in which teachers verbally supported the integration of disciplines to help students to engage in STEM+CS activities. Results indicated that, across lessons, teachers most commonly added verbal support for the integration of mathematics. In the science lesson, the majority of the instances were added and explicit; there were no instances of planned support that were made explicit. In the computer science lesson, most instances were added and implicit; planned instances were evenly split between being made explicit or implicit. Teachers also reported several challenges within less familiar disciplines, including struggling to identify and support foundational skills and enact pedagogical strategies. Implications of this study include recommendations for support that teachers need to engage in the important, but challenging, work of enacting STEM+CS curricula within elementary science classrooms.

Keywords: interdisciplinary, teachers' verbal support, elementary

National frameworks for science education in the United States (e.g., American Society for Engineering Education (ASEE), 2020; *Framework for K-12 Science Education;* National Research Council, 2012) have worked to bring science, technology, engineering, mathematics, and computer science (STEM+CS) disciplines together through curricula in K-12 classrooms (ASEE, 2020; Computer Science Framework, 2016; NGSS Lead States, 2013). Through these STEM+CS efforts, teachers are asked to support students in activities that focus on the inclusion of diverse disciplinary practices such as using mathematics and computational thinking to develop and use computational models in science and the inclusion of engineering design alongside scientific practices (e.g., Johnson et al., 2021). Moreover, integrating STEM+CS involves supporting students to engage in authentic STEM+CS disciplinary practices or practices that STEM+CS professionals use in disciplinary work. For example, the *Framework* and Next Generation Science Standards (NGSS) describe a STEM+CS vision involving students using mathematics and developing mathematical models to solve authentic problems and create scientific arguments and explanations as scientists, engineers, and computer scientists do (National Research Council, 2012*;* NGSS Lead States). Yet, this kind of deep integration is rarely seen in K-12 STEM+CS education (Kaya et al., 2019; Watkins et al., 2018).

Teachers play a crucial role in the implementation of STEM+CS curricular materials (e.g., Natarajan et al., 2021). Teachers take curricular materials and make instructional decisions for what to use in their classrooms as well as how the materials are translated to their specific contexts (e.g., Remillard & Heck, 2014). A number of factors influence how teachers plan to use STEM+CS materials, including teacher knowledge, beliefs, and epistemological frames (e.g., Gess-Newsome, 2015). Teachers make in-the-moment instructional decisions based on these and other factors in response to different classroom contexts and various perceived needs of students. Thus, teachers' *classroom enactment* involves the specific teacher-student interactions around activities and tasks during actual instruction (e.g., Remillard & Taton, 2013). Focusing on classroom enactment of STEM+CS curricular materials is important as research demonstrates that teachers need support to enact interdisciplinary curricular materials effectively (e.g., Morris et al., 2021). With STEM+CS curricular materials, teachers need to understand: individual science, engineering, mathematics, and computer science disciplines and practices; pedagogical strategies for how to support students to learn these individual disciplines and practices; how the disciplinary concepts and practices can be used together in interdisciplinary activities (e.g., Weintrop et al., 2016); and how to support students to engage in and understand these interdisciplinary activities.

Despite research on factors that influence classroom enactment of curricular materials (e.g., Christian et al., 2021; Hayes et al., 2019; Holthuis et al., 2018; Kaya et al., 2019; Lowell et al., 2021), few studies explore the complexity of classroom enactment of interdisciplinary STEM+CS curricular materials and privilege teacher voice (Lilly, McAlister, et al., 2021). In this descriptive case study, we focused on classroom enactment of interdisciplinary STEM+CS curricular materials in the form of an NGSS-aligned science project that integrates engineering, mathematics, and computer science concepts and practices. In this project, teachers supported students to investigate the world around them (science), create mathematical models of science phenomena (mathematics), apply scientific ideas to generate solutions (engineering) and develop computational models to optimize their designs (computer science).

In particular, we sought to describe how teachers enacted STEM+CS curricular materials by capturing the extent to which they used planned interdisciplinary supports as well as any added interdisciplinary supports in response to the students in their classroom context. Specifically, we focused on the specific verbal supports that two teachers used to explain how and why disciplines (i.e., science, engineering, mathematics, and computer science) work together through classroom observations of an NGSS-aligned project. We also reported on the teachers' perceptions of their enactment of the NGSS-aligned project, their perceptions of the interdisciplinary curricular materials, their own characteristics, and the classroom contexts. Our goal was to provide insight into the factors that may affect teachers' enactment of interdisciplinary STEM+CS curricular materials and the skills that teachers may need to implement interdisciplinary STEM+CS projects in elementary science classrooms.

Background

Interdisciplinary STEM+CS Integration

Implementing interdisciplinary STEM+CS projects can be challenging, because there is not a standard definition for interdisciplinary STEM+CS curricula (e.g., Breiner et al. 2012; Estapa et al., 2017; Holmlund et al., 2018; Honey et al., 2014; Roehrig et al. 2012). Some definitions of STEM+CS integration are broad, defining STEM+CS integrated curricula as between two or more STEM+CS disciplines or a STEM+CS discipline and another academic discipline (Sanders, 2012). Similarly, the National Research Council's 2014 report, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, provides the following definition of STEM integration:

> Rather than a single, well-defined experience, it involves a range of experiences with some degree of connection. The experiences may occur in one or several class periods, or throughout a curriculum; they may be reflected in the organization of a single course or an entire school, or they may be presented in an after or out-of-school activity (National Research Council, 2014, p.39; Honey et al., 2014).

These different STEM+CS curricula definitions can lead to difficulties in both achieving agreement between stakeholders on what the goals of disciplinary integration are (Berland, 2014; Estapa et al., 2017; Honey et al., 2014; Roehrig et al., 2012) and for providing teachers with support for engaging students in interdisciplinary activities. The acronym *STEM+CS* can even be used as a slogan tied to policy enactment (Bybee, 2013). Additionally, individual STEM+CS curriculum are often based on specific contexts (Bybee, 2013) or rely on the stakeholders involved (Breiner et al., 2012). Specificity to context and stakeholders can also lead to valuing different aspects of STEM+CS integration. For example, some stakeholders believe that interdisciplinary curricula should include standards and practice-based mathematics and science content that support engineering design experiences (Moore et al., 2014) or that full integration within a single class is the optimal goal (Stohlmann et al., 2012). Others believe that interdisciplinary STEM+CS is instruction that takes place in a main subject area and in at least one other subject area in ways that “encourage students to integrate and use the new knowledge and skills from several areas of competence” (Furner & Kumar, 2007, p. 187). This may work in opposition to integrating and reviewing skills from a different subject area in which students are already proficient.

These definitions support the belief that students should use skills of one discipline to support their ability to understand concepts and practices in another discipline; one subject will often be the main subject of concern and the other subjects will play a supporting role (Fitzallen, 2015). Definitions of STEM+CS integration that promote a spectrum of degrees and types of integration afford more opportunities for disciplines to be used in conjunction with each other. However, these definitions also concede varying degrees of representation of each discipline within interdisciplinary STEM+CS work (English, 2016) and the concern that not all disciplines will be adequately incorporated (Shaughnessy, 2013).

Because there are so many definitions and conceptualizations of STEM+CS integration, we defined STEM+CS interdisciplinary curricula in this study as instructional activities to be implemented within a single classroom environment that create connections, use disciplinary practices and concepts in conjunction, and focus on authentic problems between multiple disciplines (Stohlmann et al., 2012). In particular, this study investigated a STEM+CS project where students engage in engineering design using scientific practices, mathematics, and computational modeling.

STEM+CS Curricular Materials

Curricular materials provide a backbone from which teachers can adopt, adapt, or innovate (e.g., Remillard, 2005), and the quality of these materials impact enactment of STEM+CS instruction (e.g., Holthuis et al., 2018; Lowell et al., 2021). Prior research promotes the importance of implementing high-quality STEM+CS curricular materials in classroom settings, stating the potential to improve students' problem solving skills and retention (Fllis & Fouts, 2001; King & Wiseman, 2001) and providing more relevant and engaging learning experiences (e.g., Frykholm & Glasson, 2005; Koirala & Bowman, 2003). For example, in a STEM+CS curricula that incorporates mathematics, students can authentically use mathematics through the context of a real-world science problem (Frykholm & Glasson, 2005) to understand

and model the relationships between scientific concepts, create and test computational models of science phenomena, and support their claims for engineering solutions with data-based evidence (Furner & Kumar, 2007; Magiera, 2013) as well as to develop their mathematical skills (e.g., Alfieri et al., 2015; Hefty, 2015).

Research also demonstrates the potential benefits for student interest and learning with interdisciplinary STEM+CS curricular materials for integrating science and engineering (e.g., Kolodner et al., 2004; Moore et al. 2014), mathematics and engineering (e.g., Burghardt, 2013), and science and mathematics (e.g., Johnson et al., 2021). By engaging in the practices of specific disciplines in their classrooms through STEM+CS curricula, students can build knowledge about the epistemological ways of thinking and reasoning inherent to each discipline (e.g., Lilly, Chiu, et al., 2021; Tytler et al., 2021), make connections across disciplines (Ke & Schwarz, 2021), and have opportunities to engage in authentic disciplinary practices, including planning and carrying out investigations, obtaining, evaluating, and communicating information, and using mathematics and computational thinking (Crismond & Adams, 2012). For example, NGSS-aligned curricular materials call for teachers to promote authentic science learning experiences by integrating disciplinary core ideas, science and engineering practices (SEPs), and crosscutting concepts into their classrooms as well as supporting students to develop mathematical and computational models (National Research Council, 2012; NGSS, Lead States 2013).

As more teachers work to follow NGSS and implement integrated engineering and computer science practices within science activities (Carr et al., 2012), curriculum materials are needed, particularly for elementary levels, that include these opportunities for students to engage in authentic practices that integrate these disciplines through NGSS standards (Carlson et al., 2014). Curricular materials often include appropriate instructional and pedagogical strategies for particular concepts, including knowledge of examples of both normative and alternative student ideas at a particular grade band and typically involve resources created by experts in the field that teachers can access and use (e.g., Cochran-Smith & Lytle, 1992).

Support for teachers' use of curricular materials may be particularly important in elementary STEM+CS instruction as elementary teachers may not have access to professional learning experiences that support their content and pedagogical knowledge for each discipline within an interdisciplinary project. For example, elementary teachers often need support to understand engineering and computer science concepts and practices, as engineering and computer science are rarely taught in elementary teacher preparation programs (e.g., Banilower et al., 2013; Webb et al., 2020; Yadav, 2017; Yasar et al., 2006).

Project-specific curricular materials may include explicit suggestions for how teachers can support students to engage in interdisciplinary STEM+CS activities (e.g., Arias et al., 2016; Davis et al., 2017), such as through a project-specific Teacher's Guide. These suggestions may include strategies for integrating concepts within and across different disciplines through educative supports with the goal of supporting teachers to develop knowledge for interdisciplinary contexts (e.g., interdisciplinary content knowledge, knowledge of NGSS and other national frameworks, discipline-specific epistemic knowledge, and knowledge of students; e.g., Radloff & Capobianco, 2021; Wendell et al., 2019). For example, an NGSS-aligned project on scientific modeling at the fifth-grade level can involve curricular materials and associated instructional strategies to support students to engage in modeling in science, engineering, and computing contexts. Through such educative curricular materials, teachers can acquire knowledge of strategies to use to represent interdisciplinary content, integrate practices, and enact instructional strategies appropriate to grade-level expectations (e.g., Lilly et al., 2020). Thus, instead of only teaching disciplinary concepts, practices, and epistemologies, teachers are now challenged with integrating multiple disciplines together in meaningful ways (Fulmer et al., 2018).

Despite the potential benefits, research rarely considers how teachers actually integrate multiple, different disciplines while enacting STEM+CS curricula. In enacting STEM+CS curricula, it is challenging work to teach integrated practices that encompass multiple disciplines, each with its own epistemologies and practices. To teach interdisciplinary content, teachers must then have the knowledge and skills to meaningfully teach each involved discipline (Furner & Kumar, 2007) which may be difficult for teachers who are unfamiliar with, or not supported in, certain disciplines (Stinson et al., 2009). Particularly for elementary teachers, who may not have a background within each discipline, incorporating engineering and computer science into a science classroom as called for by the NGSS may be difficult. Specifically, teachers may not have prior experience or knowledge about how to engage in the practices of these disciplines themselves let alone knowledge of how to support students to engage in disciplinary practices. For example, teachers can have difficulties knowing how long lessons will last, knowing how to best guide students in their work, and maintaining confidence in their teaching (Stohlmann et al., 2012).

Further, the presence of a discipline in an activity does not guarantee that students will learn disciplinary-focused practices or concepts. For example, it is difficult for teachers to improve mathematics learning outcomes in STEM+CS environments (Becker & Park, 2011), to support students to explicitly communicate their mathematical ideas, and to maintain an appropriate level of engagement and age-appropriate mathematical difficulty level (Alfieri et al., 2015; Lilly et al., 2020; Schmidt & Houang, 2007). Thus, research considering teachers' enactment of STEM+CS curricula is important, particularly as elementary science teachers may need support to implement projects that integrate engineering design with mathematical and computational thinking (Purzer et al., 2014). Moreover, understanding how teachers enact STEM+CS curricula in elementary classrooms, perceived challenges that teachers face, and perceived support that teachers suggest is critical to engaging elementary students in rich and effective STEM+CS experiences.

Characteristics of Teachers

Teacher characteristics, such as teacher knowledge (e.g., Shulman, 1986), and beliefs about the different domains, themselves, and their students, can also affect classroom enactment of STEM+CS curricular materials (e.g., Gess-Newsome, 2015; Prescott et al., 2019). First, teacher knowledge (e.g., interdisciplinary content and pedagogical content knowledge for teaching, epistemic knowledge, knowledge of students, and curricular knowledge) are necessary for teachers to provide students opportunities to engage authentically with each discipline in an interdisciplinary context (McNeill & Krajcik, 2008). This type of knowledge builds upon teachers' pedagogical content knowledge about teaching specific disciplines (e.g., Ball et al., 2008; Grossman, 1990; Marks, 1990) and extends to include understanding how to teach disciplines in integrated ways as well as helping students to recognize how practices from multiple disciplines to support one another (Lilly, Chiu, et al., 2021). For example, teachers may need to understand how and why analyzing and interpreting mathematical data can be useful when designing a solution for an engineering problem in the real-world to help students to authentically engage in these practices within a classroom context.

Teachers' implementation of interdisciplinary curricula can also be affected by the ways in which their beliefs (e.g., attitudes about teaching, specific disciplines, and students; Muijs & Reynolds, 2002), prior knowledge, orientations, and self-efficacy (e.g., Kaya et al., 2019) can influence their instructional decisions. Regarding the interdisciplinary nature of STEM+CS instruction, teachers' prior experiences with problem-based or practice-based instruction and their comfort in supporting these types of instruction, can affect teachers' classroom enactment. For example, a teacher who, through preservice and/or professional development opportunities, has experience both engaging in computer science concepts and practices themselves as well as examples and training in how to support students in these concepts and practices may have more agency in modifying interdisciplinary curricular materials toward their individual classroom contexts and students than teachers who have limited prior experiences with computer science (e.g., Christian et al., 2021; Hayes et al., 2019).

Teacher beliefs also include self-efficacy to teach concepts and practices from different disciplines (Johnson et al., 2021; Muijs & Reynolds, 2002). For example, teachers may think a topic like computation is important to include in their classroom but not feel efficacious in teaching computation. Or if teachers believe that they are less capable of engaging in computational modeling practices themselves, they may then offer less support to students attempting to develop computational models of science phenomenon. In these ways, teachers' decisions in how they use, modify, or reject suggestions in curricular materials when enacting STEM+CS projects can affect the types of support that they offer (e.g., Remillard, 2005).

Classroom Context

Classroom contexts, including assets and resources that students bring to the classroom, school setting, community resources, and district and state requirements, can also affect classroom enactment of curricular materials. Within specific classroom contexts, teachers can use the assets of individual students to personalize learning opportunities (e.g., Mejia et al., 2020; Shelton, 2021) and make instructional decisions to enact curricular materials to meet student needs (Lilly et al., 2021; Shin et al., 2021). For example, teachers may notice that students struggle to create scientific predictions and decide that students need more explicit instruction about how and when to make predictions regarding a science phenomenon; this can lead the teachers to provide epistemic support (Lilly et al., in press) about how scientists make, adjust, and use predictions when planning and carrying out investigations.

Enactment of STEM+CS materials can also be affected by the larger school context. For example, based on the priorities of their school or district, teachers may have different levels of access to resources for interdisciplinary instruction or support from school and district level administrators for time to attend professional development or work with national STEM+CS frameworks. Teachers also may struggle to support strategies within NGSS-aligned instruction (i.e., student-led discussions, iterative design) if their school focuses on test preparation for standardized tests, particularly if their school is not in a state that has NGSS standards. Thus, the classroom and school context also affects how the teachers use different supports for students during enactment (e.g., Lilly, McAlister, et al., 2021).

Verbal Support for Enacting Interdisciplinary STEM+CS Curricular Materials

In this study, we investigated teachers' enactment of an NGSS-aligned, STEM+CS project by focusing on teachers' verbal supports for interdisciplinary integration; that is, the words that teachers say to integrate disciplines as well as to help students engage in interdisciplinary activities (Barab & Luehmann, 2003). Within the context of NGSS, verbal supports can make activities more accessible by supporting student understanding of key ideas, change the complexity of tasks that involve science and engineering practices and/or crosscutting concepts, help students make connections between their everyday lives and STEM+CS content, and develop students' background disciplinary knowledge (Krajcik et al., 2000; Reiser & Tabak, 2014). For example, to support students to analyze data and compare solutions, a student likely will need support to develop a data table that makes the differences between the solutions clear and to find patterns in similarities and differences across those solutions.

Verbal supports can be included through educative curricular materials that provide suggestions for how teachers can help students integrate disciplines. However, the accessibility of the educative curricular materials, classroom context, and teachers' perceptions about students, disciplines, and pedagogical orientations may affect the verbal supports that teachers actually give to students during classroom enactment (Lilly, Chiu, et al., 2021). Teachers can use the planned supports in the curricular materials and also add their own verbal supports, using their knowledge of their students, context, and classroom, to address the needs of their students in consideration of classroom context.

For both planned and added verbal supports, teachers can make their support either explicit or implicit, which we define based on whether teachers used verbal supports to help students understand how and why disciplines work together in an activity. Research highlights the utility of explicit support of interdisciplinary integration. For example, mathematics is often implicitly integrated in STEM+CS activities (Alfieri et al., 2015) and often takes the form of calculations or data representations (Baker & Galanti, 2017). However, making mathematics more explicit could change the student perspective from only focusing on a contextualized problem to a more authentic use of mathematics and disciplinary epistemologies (Fitzallen, 2015). In some cases, when mathematics content and connections are not made explicitly clear in STEM+CS projects (Alfieri et al., 2015; Baker & Galanti, 2017; Silk et al., 2010), then mathematics may seem so secondary to the purpose of activities in a project that teachers can give mathematics tasks less focus or even skip mathematics activities without realizing the implications for other tasks in the project (Lilly et al., under review). Instead, the mathematics must be clear (Shaughnessy, 2013) to both teachers and students (Estapa et al., 2017) to support students to make explicit connections between their mathematics learning and STEM+CS learning (Duschl et al., 2016). Thus, teachers can use planned verbal supports from the Teacher's Guide or add their own verbal supports either implicitly or explicitly to enact interdisciplinary, STEM+CS curricular materials.

Purpose

Given the emphasis on teachers supporting students to understand and engage in authentic practices within and across STEM+CS disciplines (e.g., Crotty et al., 2017; Wendell & Rogers, 2013), more research is needed to understand how elementary teachers provide implicit and explicit as well as planned and added support in elementary classrooms. This study examined how elementary teachers help students engage in STEM+CS activities by exploring how teachers use verbal supports to integrate STEM+CS disciplines during an elementary NGSS-aligned project. Specifically, we investigated the following research questions:

RQ1: In what ways do elementary teachers verbally support the integration of science engineering, mathematics, and computer science into the lessons of an interdisciplinary STEM+CS project and to what extent are these supports planned in curricular materials or added in-the-moment?

RQ2: What were teachers' perceptions of supporting students to engage in integrated disciplines throughout their enactment of an interdisciplinary STEM+CS project?

Methods

We considered two fifth-grade teachers' verbal support of interdisciplinary integration using a single case study (Yin, 2018) of the classroom enactment of an interdisciplinary STEM+CS project. We chose to use a descriptive, single case study methodology in order to describe how two elementary teachers with science backgrounds co-taught an NGSS-aligned, STEM+CS project in a single, bounded context (Miles et al., 2020). This is a unique case (Yin, 2018) of the enactment of an STEM+CS project as the fifth-grade teachers had undergraduate science degrees and were familiar with the curriculum developers' goals for the project as they had helped to develop and implement a pilot version of the project.

Setting and Participants

The study context was a public upper elementary school in which students were classified as: 38% Black, 38% White, 13% Hispanic, 6% Asian, and 5% Multiple Races; 18% of students receive Special Education Services, 17% were Emerging Bilinguals, and 53% qualified for free or reduced-price lunch.

At this elementary school, two fifth-grade science teachers, Mr. Skelton and Ms. Banet (pseudonyms), co-taught a four-week STEM+CS project. Both teachers have over five years of teaching experience; at the time of implementation, Ms. Banet was a classroom science and mathematics teacher while Mr. Skelton was the school's STEM coordinator.

In this study, we considered a single implementation of an interdisciplinary project in two fifth-grade classrooms. Together, the teachers implemented each lesson of this project first in Class A (which had a larger percentage of students in advanced mathematics) and then in Class B (which had a larger percentage of students with individualized education plans). In this study, we combined data from both classrooms as there were no patterns that emerged across classroom contexts. This led us to make limited comparisons across the two classrooms, which was important to ensure that we did not infer that inconsistent differences in teachers' verbal support are a result of a more inclusive classroom setting.

STEM+CS Curricular Project

Within the four-week, STEM+CS project, students integrated science, engineering, mathematics, and computer science by redesigning their school grounds to reduce water run-off by investigating surface materials, generating multiple design solutions, and testing their designs using computational modeling (Chiu et al., 2019). The project was co-designed with teachers and district leaders to be based around specific NGSS Performance Expectations and was refined after pilot implementations at the same school with the same teachers.

Data Sources

The primary data source was transcripts of whole class discussions from three disciplinary-focused lessons that were taught over twelve class periods and focused on science (six class periods), engineering (three class periods), and computer science (three class periods), respectively (Table 1). Within the project's interdisciplinary curricular materials, the discipline of mathematics was integrated throughout these lessons, with no explicitly mathematics-focused lesson.

Table 1

Summary of Disciplinary-Focused Lessons

Disciplinary Focus	**Length (days)**	**Learning Objectives**
Science	6	Students will show how surface materials affect the absorption of water by carrying out investigations and analyzing data, and then use data as evidence to support a related claim while constructing an explanation.
Computer Science	3	Students will understand the utility of computational modeling through developing, interpreting, and testing a computational model that relates rainfall, runoff, and water absorption.
Engineering	3	Students will address the problem of water runoff by generating multiple design solutions and communicating how these solutions meet the criteria of the design challenge

Data sources included transcriptions of audio recordings that documented all whole-class discussion. We used the transcriptions to explore instances of verbal support for interdisciplinary integration for each class section within each of the three lessons.

Additionally, the Teacher's Guide for the project served as a data source of interdisciplinary curricular materials. The Teacher's Guide included lesson plans, interdisciplinary pedagogical strategies, and suggestions for how to integrate disciplines in classroom enactment. We used the Teacher's Guide to determine if verbal support for integrating disciplines was planned for teachers in the curricular materials or if teachers added their own verbal support to integrate disciplines.

Daily written surveys and weekly face-to-face interviews with Mr. Skelton and Ms. Banet served as the final data source. These surveys and interviews asked teachers six open-ended questions to capture their perspectives on curriculum implementation, better understand their perceived successes and struggles, their perceptions of students' successes and struggles, changes that they made to the lesson to support students' learning, and what, if any, additional support they feel would have been helpful through professional development (Appendix). In the interviews, teachers were asked the same six questions, but asked to reflect across the past week rather than just a single day. This allowed the teachers to expand and explain ideas in more detail than the written surveys were able to capture as well as attend to validity through an additional data source. We used the surveys and interviews to consider teachers' perceptions of enacting the STEM+CS project.

Data Analysis

Identifying Instances of Interdisciplinary Integration

To analyze the teachers' classroom enactment of the STEM+CS project, two researchers read the transcript of each disciplinary-focused lesson and identified passages of whole-class discussion. Within the whole-class discussion, the researchers then identified instances of interdisciplinary integration when the teachers provided verbal support to integrate scientific, engineering, mathematical, or computational concepts or practices. A single instance could include both teachers' verbal support and student responses, beginning when a teacher verbally supported the integration of two or more disciplines within whole-class discussion and ending when the discussion either shifted to a new topic or ended. Each of these instances were considered as separate units of analysis. Specifically, two researchers discussed each instance of interdisciplinary integration and coded which disciplines were integrated, the SEPs that the teachers verbally supported, the disciplinary-focused lesson, their chronological order, and the class in which they occurred.

Coding the Verbal Support of Instances of Interdisciplinary Integration

To understand patterns across the instances of interdisciplinary integration, the researchers then created a four-quadrant, analytic framework for coding verbal support of interdisciplinary integration, divided along an axis of explicit or implicit support and an axis of planned or added support (Figure 1; Lilly, McAlister, et al., 2021).

Figure 1

Quadrants of Support Based on the Added-Planned and Explicit-Implicit Axes (Lilly, McAlister, et al., 2021)

Explicit

	Quadrant II	*Quadrant I*	
	Teachers add support for an instance of integration in implementation; this integration is made clear to the students.	Teachers implement integration written into the curriculum; this integration is made clear to students.	
Added			**Planned**
	Quadrant III	*Quadrant IV*	
	Teachers add support for an instance of integration in implementation; this integration is not made clear to students.	Teachers implement integration written into the curriculum; this integration is not made clear to students.	

Implicit

First, through team coding (Miles et al., 2020), two researchers assigned codes to each instance of interdisciplinary integration to identify whether integration was *explicitly* explained to students or if it was *implicit* in the larger discussion. We defined *explicit* integration to be when teachers' verbally supported students' understanding of why and how the disciplines were working together in an activity. We defined *implicit* integration to be when teachers' gave verbal support for students to engage in multiple disciplines within an activity but did not explain why or how the disciplines were working together.

The researchers then coded whether an instance of interdisciplinary integration was *planned* in the curricular materials or *added* by the teachers. The researchers defined *planned* integration as that which was included within the written project curricular materials given to the teachers. To identify if an instance of interdisciplinary integration was planned, the researchers searched the text of the Teacher's Guide in the relevant lesson for a written explanation for that particular instance of integration. For example, in Table 2, we present an instance of planned integration that took place in the computer science lesson by showing the alignment between a teacher's verbal support and the corresponding text from the Teacher's Guide in the same lesson.

Table 2.

Planned Instance of Interdisciplinary Integration: Enacted by Teacher and Corresponding Suggestion in Teacher's Guide

Enacted Planned Instance of Integration	Suggestion in Teacher's Guide
We need to think about what we want our model to do based on what we've already learned from some of our experiments. First, what is a variable or what is, think about in your math classes? How would you define that term before? - Mr. Skelton CA.25, Figure 4	**Discussion goal:** To introduce and familiarize computer programming concepts such as variables, initial value, change rule. **Opening prompt:** Ask students what they know about variables. *[Likely they have experience with experiments, or they have heard the term as something that changes. They might have seen it in Math.]* In computer programming, amounts or values that change are called "**variables**". What are some amounts or values that we need to keep track of for our model? *[Look back at your conceptual model for help.]*

The researchers defined *added* integration as verbal support that teachers gave for interdisciplinary integration that was not included in the written curricular materials; specifically, if there was no corresponding suggestion in the Teacher's Guide for an instance of interdisciplinary integration.

As two researchers considered each instance of interdisciplinary integration, they wrote a memo describing the instance of interdisciplinary integration and their discussion of the coding of that instance. Additionally, to strengthen the validity of this analysis, the researchers consulted with the curriculum designers to ensure alignment between coding and the intended support for teachers offered within the curriculum materials.

Visualizing the Instances of Interdisciplinary Integration

The researchers then used the assigned codes to place each instance of interdisciplinary integration in quadrants defined by the axes of explicit vs. implicit and planned vs. added (e.g., Figures 2, 3, and 4). In creating these visualizations, the researchers labeled each instance by the disciplinary-focus of the lesson (S for science, E for engineering, and C for computer science), the class (A for Class A and B for Class B), and its chronological order within a disciplinary-focused lesson (e.g., SB.2 is the second instance of interdisciplinary integration for Class B within the science lesson). For each graph, the researchers grouped their previous memos by quadrant and used pattern coding to look across instances of interdisciplinary integration for emerging themes (Miles et al., 2020).

Analyzing Teacher Reflections

Over the four-week project, both teachers answered open-ended questions on daily written surveys and weekly interviews about project implementation. Two researchers inductively coded (Miles et al., 2020) the surveys and transcripts of the audio-recorded interviews. For first level coding, the researchers read and discussed each answer to identify if a response demonstrated a reflection on interdisciplinary integration by including teachers' perspectives about (1) STEM+CS disciplines or (2) implementation of the STEM+CS project. These discussions were also used to build operational definitions for possible second level codes based on the data.

For second level coding, the researchers considered each response that demonstrated a reflection on interdisciplinary integration to code teachers' perceptions about the following: challenges and successes in integrating disciplines, challenges and successes in supporting students to engage in integrated STEM+CS disciplines, changes made to STEM+CS activities to support student engagement, and additional support needed to enact STEM+CS activities. The researchers then looked across coded statements for patterns and wrote analytic memos that became the basis for the findings below (Miles et al., 2020). To increase validity, we presented initial findings from the engineering lesson only for feedback from other scholars in STEM+CS (Lilly, McAlister, et al., 2021). Using this feedback to modify our framework of teacher enactment and add analysis of teacher perceptions, we extended analysis of instances of interdisciplinary integration to the science and computer science lessons. Below, we share findings broadly across the three disciplinary-focused lessons and focus individually on findings from analysis of the science and computer science lessons; findings from the engineering lesson are shared in detail separately (Lilly, McAlister, et al., 2021).

Findings

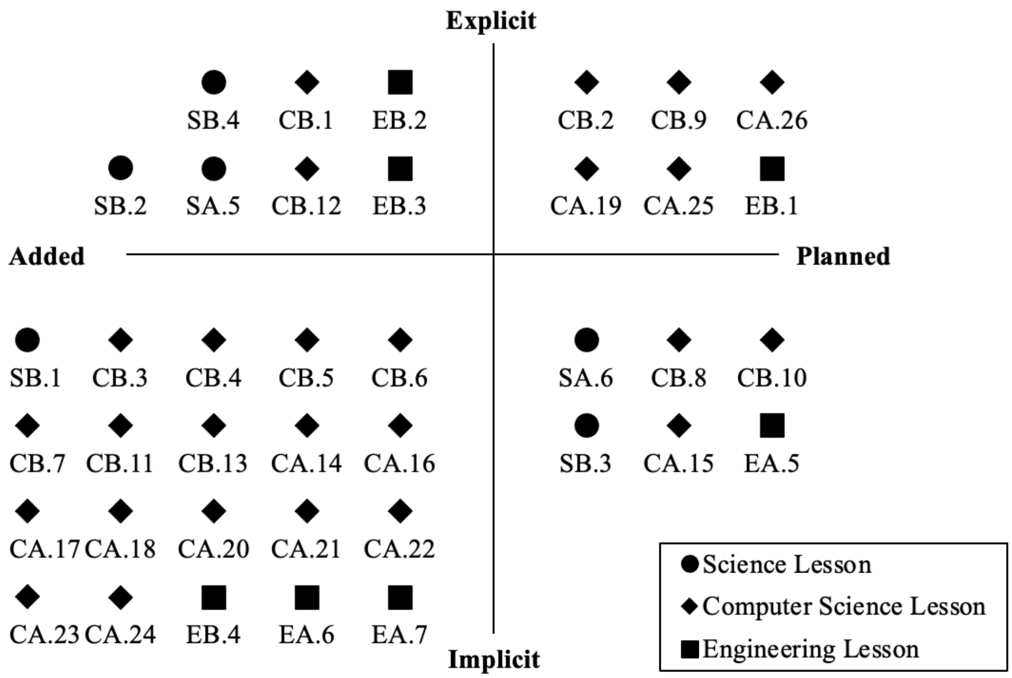
RQ1: In what ways do elementary teachers verbally support the integration of science engineering, mathematics, and computer science into the lessons of an interdisciplinary STEM+CS project and to what extent are these supports planned in curricular materials or added in-the-moment?

Across Lessons

Across the science, computer science, and engineering-focused lessons, most of the instances of interdisciplinary integration were implicit rather than explicit. Additionally, most of the instances of interdisciplinary integration were added rather than planned. Thus, overall, the majority of instances of integration are added and implicit (Quadrant III). Of the planned instances, they were evenly split between being made explicit or implicit. Most of the instances of integration occurred in the computer science lesson, while the science lesson had the fewest (Figure 2).

Figure 2.

Instances of Integration by Lesson located in Quadrants of Support



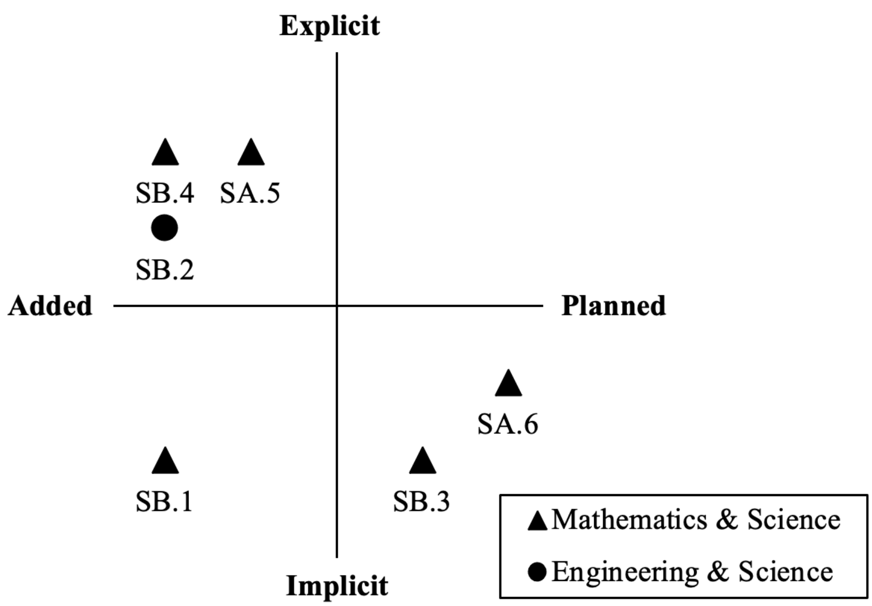
Note: Each disciplinary-focused lesson (i.e., science, computer science, engineering) is indicated by a shape, as shown in the key above. All instances of integration are labeled by lesson and placed within their quadrant based on the dichotomized spectra of explicit vs. implicit and planned vs. added.

Science Lesson

In the science lesson, instances of interdisciplinary integration were typically integrating mathematics with science (Figure 3). The majority of the instances of mathematics integration were added (Figure 3; Quadrants II and III), and three of these four added instances were made explicit (Figure 3; SB.2, SB. 4, SA.5). There were no instances of planned support that was made explicit. Further, there were no instances of computer science integration in the science lesson.

Figure 3.

Instances of Integration in the Science Lesson by Disciplinary Integration.



Note: The type of disciplinary integration in each lesson (i.e., science with engineering, computer science with mathematics, engineering with science and computer science) is indicated by a shape, as shown in the key above.

Planned Support. In the science lesson, the teachers provided two instances of *planned* support, one in each class section. This support matched the Teacher's Guide specific suggestion of an opportunity for teachers to provide a "Math Connection" as a way for teachers to help students to "reason additively" when thinking about the complement of the ratio. In both instances (SA.6; SB.3), Mr. Skelton and Ms. Banet *implicitly* supported students to use mathematics concepts of proportions and fractions to support an understanding of the science concept of absorption ratios under the SEP of *using mathematics and computational thinking*.

First, the teachers led the students through how to use the absorption ratio. For example, in Class A (SA.6), Ms. Banet said, “Using the absorption ratios from above, calculate how much water would be absorbed by filling up the table below. So we have concrete and rubber tiles. Concrete's absorption ratio is fifteen hundredths, rubber tiles absorption ratio is fifty-five hundredths.” A student in Class A extended upon this support by making an added connection to their prior experience in mathematics class, saying, "I have a connection, is that the same thing as adding fractions?" We did not count this as a separate instance as it was a student, not the teacher, who offered the verbal support of the integration. The mathematics was distinct and obvious enough that it supported students to spontaneously note the integration of what they have learned in their mathematics class to what they were learning in the current science lesson. This connection was initially driven by the students, rather than the teacher, but the opportunity for a connection was purposefully built into the curriculum by members of the curricular-building team who are experts in mathematics education.

The teachers enacted the same planned support of absorption ratios in Class B (SB.3). Then, as discussed below, the teachers also added support in Class B (SB.4) based on the student’s connection from Class A.

Added Support. There were four instances of added support for interdisciplinary integration in the science lesson. One instance (SB.4) occurred alongside the teacher's support of planned integration to Class B (SB.3). Here, Ms. Banet added an explicit instance of interdisciplinary integration based on the student’s connection from Class A saying, "this is very similar to the skill that we just practiced. Adding and subtracting fractions. That's how you figure out what was absorbed versus what stays on top" (SB.4).

In both classes, the teachers also added an instance of interdisciplinary integration (SB.1 and SA.5) to verbally support the integration of the mathematics concepts of average and subtraction to support students to engage the SEP of *analyzing and interpreting data* from the science investigation. In Class B, the teachers made this support implicitly (SB.1) saying “So then you guys have to measure the total amount of water on top, and then using your subtraction skills, figure out the total amount of water soaked in.” In Class A, this support was made explicit to students (SA.5) as Mr. Skelton had students recall concepts from their mathematics class, reminding students that average is the same as the mean, and explicitly spoke about how they can be used in science:

> So 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 we take an average, or the mean like in math class, because we want to find like where is the center point. Where's the best measure of central there.

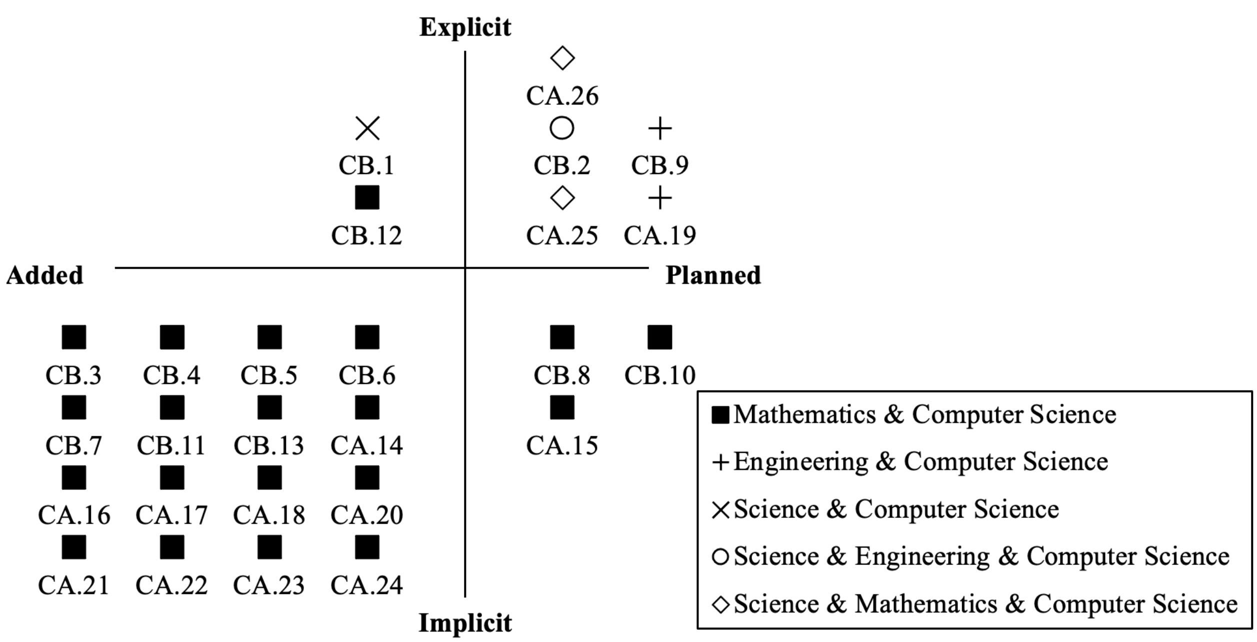
There was one other explicit instance of integrating science and engineering in the science lesson (SB.2). Here, Mr. Skelton made explicit to Class B how the science concepts of absorption of different materials that students had been learning in their investigations would inform their future engineering designs, “You're finally going to get to see the materials you're going to get to use to actually redesign the grid.” This was not part of the planned curriculum and was not similarly presented to Class A. Instead, this instance was added by teachers to help students in Class B connect their science activities to future engineering activities.

Computer Science Lesson

In the computer science lesson, most instances were implicit, added, and focused on integrating mathematics and computer science (Figure 4). Of the added instances, they were rarely made explicit. Only one instance of added support did not integrate mathematics; there was no added support that integrated engineering in the computer science lesson. Of the planned instances, they were evenly split between being made explicit or implicit. There were also several examples of integration happening between more than two disciplines within a single instance such as integrated science and engineering and computer science as well as integrated science and mathematics and computer science.

Figure 4.

Instances of Integration in the Computer Science Lesson by Disciplinary Integration.



Planned Support. First, we consider *planned* support that *implicitly* included the integration of mathematics. For example, teachers supported students to *use mathematical and computational thinking* integrated in their computer science activity as they walked students through the mathematical operations going on inside a loop (CA.15). Mr. Skelton says "Let's do a little table calculation over here to help you understand a little bit more about what this means," which is a strategy suggested by the Teacher's Guide for helping students to use mathematics to understand computer science. The teachers similarly offered this type of implicit mathematical support for understanding the looping function throughout the computer science lesson in Class B (CB.8; CB.10).

Next we consider *planned* support that *explicitly* included the integration of mathematics. To support students to *use mathematics and computational thinking* within the computer science lesson, Mr. Skelton explicitly supported students to consider what they learned about mathematical variables in the science investigations to make decisions when designing their computer models (CA.25; CA.26). In both of these instances, he explicitly told students the connection between their current computer science activity about variables in computer codes, and the times in science and mathematics classes when they have used the term 'variable' before.

In CA.25, Mr. Skelton first engaged students' prior knowledge saying,

> We need to think about what we want our model to do based on what we've already learned from some of our experiments. First, what is a variable or what is, think about in your math classes? How would you define that term before?

This was in line with the Teacher's Guide's suggestion to "ask students what they know about variables. Likely they have experience with experiments, or they have heard the term as something that changes. They might have seen it in Math."

Later in the lesson (CA. 26), Mr. Skelton gave explicit verbal support to build upon students' prior knowledge of variables. First he supported students to understand how they would be using variables in the computer science activity saying, "So we don't really define [variables] as specifically as we do in science. It's really just a number that can change or a value that can change if you want to think about it that way." He then encouraged students to apply their knowledge and begin to create variables for the computer model. To do this, he said "I want you to think about which variables or amounts of things we track for our model. Our computer models go all the way back to the beginning of when we started doing experiments. And let's think about some variables and things that you'd change that we actually want to be able to track in our computer model." He then engaged students in a whole-class discussion to brainstorm variables for their computer models. Through these instances of interdisciplinary integration, Mr. Skelton supported students to situate a new definition of variables by comparing it to the ways they have used the term previously in their science and mathematics classes. This is an example of the teachers explicitly integrating students' understandings from the disciplines of mathematics and science into their understanding of computer science as suggested by the Teacher's Guide.

Finally, we consider *planned* support that was *explicit* but did not include the integration of mathematics. In considering planned support for science, engineering, and computer science, the teachers explicitly helped students by considering how science knowledge informs the development of computer models, and why scientists and engineers benefit from using such models. In Class B (CB.2), Mr. Skelton says

> Computers make things so much easier for us. Back before we had this technology, we would actually have to build a different version of all of these designs if we wanted to test them out. Now, for example, if you wanted to test out a brand new car, we actually make a computational model or a design of the car, and then use experimental data, like you guys did the other day where we tested out the grass versus concrete, that was experimental data. So these guys use experimental data in their models to try to test out how new cars would behave... and they all do this on a computer instead of having to build each different version of a car.

This explicit support is outlined in the Teacher's guide, which provided the following script for teachers to use:

> How will you know if your playground design "works"--that it meets all the design criteria? Do you have to actually build it and wait until it rains to find out? That wouldn't be very practical. Computers can help. Computers can help you test designs that you can't test with real materials because it would be too hard or expensive. Scientists and engineers often use computers to make models to help them make predictions ...

In Class A, teachers provide similar support but only for the integration of science and computer science. This instance still motivated the use of computational models; however, the teachers prompted students to arrive at important conclusions on their own (CA.19). In this instance, a student makes the point that testing the playground designs in real life "will take too much time and plus you're going to have to make everything and be expensive." Mr. Skelton verified the student's response by discussing how cars can be scientifically tested using computational models to determine safety protocols and levels of comfort for drivers (CA.19) and connecting these applications to the students' scientific experiments and computational tests for water runoff to support this integration of science and computer science but without engineering.

The teachers supported students in integrating science and computer science in one instance in Class B that was not presented in Class A. The Teacher's Guide suggests that teachers "wrap up the lesson by ... giving a heads up for the following lessons where they will create computer models of their design and run tests on them." Thus, at the end of the computer science lesson, Ms. Banet connected the purpose of using computational models to the engineering designs that students created earlier (CB.9). "If you're wondering ‘where are we going to go from here?’ On Monday, when you guys come back, you're actually going to be able to test the design that you put in your book with the surface materials." This laid the groundwork for further integrating these two disciplines in the engineering lesson.

Added Support. The majority of instances of interdisciplinary integration in the computer science lesson were *added* and *implicit*. First, each of the added, implicit examples integrated mathematics. Each added, implicit example either supported students to engage in *developing and using models*, *using mathematics and computational thinking*, or *analyzing and interpreting data*. Since there were many instances of the same type of support, we note all of the instances but only include one example for each SEP.

First we consider added, implicit instances of interdisciplinary integration that supported students in *developing and using models* (e.g., CB.3, CB.4, CB.5, CB.6, CB.13, CA.14, CA.17, CA.18, CA.20, CA.22, CA.23, CA.24) by sharing an example from Class A (CA.24). In this example, Mr. Skelton implicitly led the students in considering how using a variable in their mathematical model of the absorption ratio enabled them to test different surface areas in their computational model. For example, in the beginning of this instance, he said, “The last thing to think about is how we're going to code all these different surfaces for their different surface areas. What are these different surfaces? How do they change? What is the thing that changes about each surface?” Later in the same instance, Mr. Skelton asked students to test their work by running the computational model and comparing results to results that they had previously calculated by plugging in different values by hand into the mathematical model. When the answers matched, he said, “So we’re right. That was adding in this piece of code right here.” In each of the instances in this category, the teachers similarly added supported to help the students in different aspects of creating a mathematical model to use in their computational model using implicit verbal support.

Next we illustrate instances of interdisciplinary integration that supported students in *using mathematics and computational thinking* (e.g., CA.16; CA.21; CB.11) through an example in which the teachers added verbal support for Class A to support students to compare equivalent mathematical models that use different operations (CA.21). Specifically, the teachers supported students to understand the relation between the mathematical additive and multiplicative operations, and that water runoff can be represented by multiple different mathematical models. They connected this to the idea that there can be multiple correct ways to code a computational model, as Mr. Skelton said, "So this is just kind of one operation instead of multiple additive operations". First, the support helped students understand that multiple additions of the same number can be represented by multiplication as their models were compared to one another. Then Mr. Skelton added,

> So you could have done it either way, which is a really important point when you're coding. There's not always one solution. As a matter of fact, there's often lots of different solutions. So if you've got here a different way, that's wonderful.

This added support implicitly integrated the mathematical models into the computer science discipline and encouraged the students that their models can all be different and correct, rather than needing to come up with the one right answer. Each of these examples of added, implicit support for *using mathematics and computational thinking* helped students to draw connections between epistemic ideas in mathematics and computational thinking, such as there is no single way to write a mathematical expression or to code a computational model.

Finally, there was one example of added, implicit support in which teachers supported students in *analyzing and interpreting data* which occurred in Class B (CB.7). Specifically, as the teachers were helping students find patterns in the tables as suggested in the Teacher's Guide, the teachers also added support to help students to understand that different surface materials have different absorption rates (CB.7). To do so, Ms. Banet asked "when we are talking about an absorption ratio up here and you're putting it into your computer, are you going to have the same ratio for every single surface?" This added support continued and focused on the integration of mathematics into this computer science lesson as students used the data of different absorption ratios for different types of surfaces to show the need for a mathematical formula with variables.

Now we consider the two instances of integration in the computer science lesson that were *added* and *explicit* and which both occurred in Class B to support students in *developing and using models*. One instance of added, explicit support integrated mathematics as Mr. Skelton added verbal support to lead students to find the total absorption in the computational model by explicitly using mathematical concepts (CB.12). This instance included student responses and teacher feedback as Mr. Skelton both explained how they were using mathematics, saying "if a computer's going to understand what total absorption means, we have to put our understanding of this into mathematical terms" and "so we have to figure out kind of like a mathematical pattern or an expression to help us understand how to include absorption in our model" as well as supported students to engage in the mathematical practices, saying, "what do we get when we multiply point seven times point three? Can you do this quick math calculation on your paper?"

The other instance of explicit added support in the computer science lesson was support of science and computer science; Mr. Skelton made it explicit for the students how the science investigations should inform their computer models (CB.1). He said that the class is "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." While this is the stated purpose of the computer science lesson in the Teacher’s Guide, making this explicit connection is not written in the Teacher’s Guide. By adding this instance, teachers worked to integrate the previous science concepts into the later computer science lesson. This was the only instance of added support in the computer science lesson that did not integrate mathematics.

RQ2: What were teachers’ reported perceptions of supporting students to engage in integrated disciplines throughout their enactment of an interdisciplinary STEM+CS project?

The teachers reported that challenges to enacting this interdisciplinary STEM+CS project included their own abilities within specific disciplines, students’ prior knowledge across disciplines, and student engagement in interdisciplinary contexts. The teachers also reported their suggestions of what they, or other teachers, may need to successfully implement future STEM+CS projects.

Challenges with Pedagogical Strategies for Disciplinary and Interdisciplinary Activities

Teachers struggled to identify and support the foundational skills that were necessary for students to engage in the engineering and computer science activities. For example, the teachers reported the challenge of explaining computational modeling to students when students were struggling to just access the modeling environment or simply save their work when building and testing their engineering designs. Ms. Banet reflected on struggling to support students to use the computational modeling program:

> Explaining to the students how to save your computer, just in case something happens to get a fresh one. Yeah, that's pretty key. Because that kept happening, it kept disappearing. So I was walking around, trying to show them. Also maybe going over how to get back using a simulation button. We should have done at the beginning of showing how to shrink and enlarge the stage. And then realizing that when they clicked out of whatever they were working on, they could hit the simulation by name and show the code again. That was really, that was a struggle. They didn't know what that was.

The teachers recognized that they did not anticipate a need for support to help set-up the students' familiarity with the computational modeling program and that students needed an additional introduction to the computational modeling program for the curriculum before they could engage in the engineering-focused activities.

The teachers also reported struggling with pedagogical strategies to support students' computational modeling. For example, Ms. Banet felt like her struggles helping debug the students' computational models had a negative impact on students' engagement with the activities, saying,

> Students' programs were malfunctioning, and I didn't know how to help other than having them close out their program and bring up a whole new copy. A couple of girls, they didn't know why it wasn't running the program ... and they ended up having to start over because I didn't know what else to do.

Both teachers discussed other challenges helping students debug their computational models, including remembering how to get into the computational modeling environment to begin an activity and then being able to troubleshoot computational issues with students throughout activities.

Additionally, teachers also found it challenging when the interdisciplinary nature of the project meant that activities used concepts from one discipline in another disciplinary context. For example, Ms. Banet said:

> A lot of the students struggled with the word *relate*. They just don't understand when you're asking ‘How does hourly rainfall relate to total amount of water’. And I just, I don't know how to simplify that myself. Or at least not in the moment I didn't know.

Similarly, even though Ms. Banet also taught mathematics classes, she reported difficulties when trying to support all students to use the mathematics concept of “ratio” with the science phenomena of absorption and run-off.

Teacher Perceptions of Student Engagement Across Disciplines

Teachers reported different perceptions about students’ engagement in activities across disciplines. For example, teachers reported that students were more engaged in science-focused activities where students performed hands-on experiments than in the computer-science focused activities. Specifically, Mr. Skelton said, “students sitting for that long and doing coding work isn't really cognitively demanding.”

The teachers also reported altering activities for time. For example, Ms. Banet reflected that, “due to time, we cut out all the math in the notebook. So the kids didn't do pages, the last page we did was 18 and then we had them skip to page 26”. This example also highlights a larger pattern; when faced with pacing concerns, the teachers often chose to remove aspects of mathematics rather than a different discipline. Additionally, the pacing of the content caused the teachers to worry that students did not understand why they engaged in specific activities. Ms. Banet said,

> I struggled to rush through the lesson without having students really understand why we were developing this model. Many students have lost interest in part because this is challenging, but also because there is a disconnect between the hands-on experiments and how this relates to the computational model.

Her concern for students' perception of a disconnect between interdisciplinary activities may have led to some of the alterations the teachers made to the curriculum.

Need for Additional Interdisciplinary Learning Experiences

Teachers also reported suggestions for support that they felt was necessary to implement the project. They reported needing additional support related to the interdisciplinary STEM+CS content, practices, and related instructional strategies. For example, Ms. Banet suggested a need for professional development in foundational skills for computer science (i.e., troubleshooting and debugging). Both teachers expressed a need for preparation or educative supports to equitably support all students to understand the mathematics concept of ratios. For example, Mr. Skelton suggested, "Even a short introduction to what a ratio is, a short video so they can see what that means. Or suggestions for how to give examples of it." He noted that this was important as ratios are an advanced mathematics concept for upper elementary students and he needed to be capable of supporting all students' to understand the underlying mathematics behind the scientific concept of absorption ratios.

Teachers also reported needing help implementing the STEM+CS curriculum to support student engagement in authentic disciplinary practices. For example, they reported feeling that their implementation of the project was too often leading students toward specific answers. Ms. Banet reflected specifically on needing support to reconcile her instinct to support students to engage iteratively in changing their ideas based on further understanding with the curriculum's more structured scaffolding to intentionally provide opportunities and support for revision:

> I think the kids kind of felt like they had to revise. But we don't want them to if they haven't come to their own senses that something should be changed. That's hard for me as the teacher guiding that conversation. I honestly think I need more professional development around how to hold that conversation and see what it will look like to effectively do it and to guide students through such a rigorous prep process. I feel like I really struggled to help them with it. And I felt like, maybe I don't understand … Do we want students to have specific answers? Or do we want them to make their own meaning and then see how they change that on their own, see how it evolves throughout the curriculum.

The teachers reported feeling challenged with facilitating STEM+CS projects in which each student may have a different model or different design.

Discussion and Implications

The results of this case study illustrated how two fifth-grade teachers enacted planned verbal support of interdisciplinary integration and added their own verbal support of interdisciplinary integration within the implementation of a NGSS-aligned, STEM+CS project (Barab & Luehmann, 2003). Results highlighted the work that teachers do to enact interdisciplinary STEM+CS curricula and tailor materials to their own classroom contexts. Teacher reflections provided insight into their perceptions of the enactment of curricular materials and how their own beliefs and the classroom context may have affected their enactment of the project.

Planned Versus Added Verbal Support

Results indicated that the teachers provided students with more added verbal supports for interdisciplinary integration than those planned in the Teachers' Guide. Teachers provided more added verbal supports for interdisciplinary integration in the computer science lesson as opposed to the science lesson. This may have been due to the timing of the computational modeling lesson, as it was after the science and engineering lessons and teachers may have used these shared experiences as supports to connect and situate the computational modeling lesson. However, it may also reflect the relatively less familiar discipline of computer science for the teachers and the students, and the needed supports to help students engage in computational modeling situated in an engineering and science context. Future research should investigate if and why these differences may occur in other settings.

However, teachers also reported that their added support may have led to activities becoming more teacher-centered. For example, the computer science lesson was planned such that students engage in the creation of mathematical models more independently than was observed. As teachers led students through the calculations and process of creating the mathematics models as a whole class, they extended their verbal support past that suggested by the curriculum to further help their students engage in mathematical modeling. But the teachers reported that this modification shifted the activities to become more teacher-centered. This finding highlights the importance of studying the enactment of STEM+CS curricular materials and how to support teachers to be able to provide in-the-moment support that aligns with the intended curricular goals (Lilly et al., in press).

Explicit Versus Implicit Verbal Support

The teachers most often gave implicit rather than explicit verbal support of interdisciplinary integration. Thus, these results highlight the support teachers may need to understand the importance of and examples of making integration explicit (e.g., Alfieri et al., 2015; Baker & Galanti, 2017; Shaughnessy, 2013; Silk et al., 2010).

Teachers were able to make verbal support of interdisciplinary integration explicit, but they were not consistent with this support across the two classes for each disciplinary-focused lesson. Teachers may need support to consistently make examples explicit, particularly by curriculum designers as the planned support was rarely explicit. However, more research is needed as different disciplines may require varying levels of supports for different students and too much support could be disadvantageous for students. For example, teachers reported struggling with providing support to explain how to program their computational models when students struggled to access the modeling environment or save their work. Additionally, even though both teachers had experience and backgrounds in science, they still reported struggling with supporting students with science concepts and practices that were part of the STEM+CS project.

Mathematics Integration

The interdisciplinary project presented STEM+CS learning not as a combining of the disciplines, but as an opportunity for students to intentionally use the products of one discipline to support learning in another discipline in line with models of interdisciplinary education (e.g., Barth et al., 2017). For example, mathematics was not a focal discipline of a single lesson in the planned curriculum; however mathematics was planned to be integrated and verbally supported to play an important role in students' learning throughout all of the lessons. This was in agreement with the ways that prior research suggests STEM+CS curricula can use authentic use of mathematics (e.g., Frykholm & Glasson, 2005; Furner & Kumar, 2007; Hefty, 2015; Magiera, 2013) and make mathematics content and connections explicitly clear (Baker & Galanti, 2017; Silk et al., 2010).

In enactment, mathematics was also the most common discipline integrated to support student engagement in the SEPs, despite there not being a lesson specifically focused on mathematics. These instances were opportunities to help students understand that mathematics is not only done in mathematics class but can also be part of science class and real-world experiences (i.e., Baker & Galanti, 2017; Frykholm & Glasson, 2005; Johnson et al., 2020; Silk et al., 2010). Teachers' reflections reveal that it may have been more natural for them to integrate mathematics based on their prior experiences, self-efficacy, and preparedness with the subject (i.e., teachers' characteristics; Plumley, 2019). For example, Ms. Banet taught both mathematics and science to many of these students; therefore, it may have been natural for her to integrate mathematics concepts into the science lesson. The teachers may not have had the same experience integrating engineering or computer science into their classroom discussion.

Integrating mathematics explicitly was a challenge for teachers. Consistent with prior research of integrated mathematics in STEM+CS activities, instances of mathematics integration were often added and implicit (i.e., Alfieri et al., 2015; Baker & Galanti, 2017). There were only two instances of explicit mathematics integration in the science lesson. These were both added and occurred one in each of the class sections. Having one instance of explicit mathematics integration in the science lesson may not have been enough for these students to strongly connect mathematics to science. This is consistent with challenges to support explicit integration of mathematics in STEM+CS activities in prior literature (i.e., Alfieri et al., 2015; Baker & Galanti, 2017; Duschl et al., 2016). Since the instance (SB.4) in Class B was in response to a student in Class A making a connection to their mathematics class, the teachers may not have otherwise made explicit that mathematics concepts can support data interpretation in science. However, by providing a learning atmosphere where a student felt comfortable sharing their connection, the teachers were able to use student ideas to adjust their instruction and include this connection in their verbal support in the other class section to meet the needs of their students (Lilly et al., under review; Mejia et al., 2020; Shelton, 2021).

Interdisciplinary Challenges Reported by Teachers

Given the emphasis on teachers supporting students to understand and engage in, authentic practices within and across STEM+CS disciplines (e.g., Carlson et al., 2014; Crotty et al., 2017; Wendell & Rogers, 2013), make STEM+CS meaningful to students (i.e., Guzey et al., 2016), and offer connections between their current lives, school contexts, and STEM+CS careers (i.e., Roehrig et al., 2012), it is important to understand and address the challenges teachers face enacting integrated curricula (e.g., Fulmer et al., 2018; Furner & Kumar, 2007). Teachers reported cutting mathematics activities early in the project that may have affected student engagement with computer science and engineering activities later in the project. Without the disciplinary knowledge to recognize how knowledge would build and the importance of specific activities for students to understand concepts and engage in activities later in the project, the teachers cut important activities due to their beliefs about their students' abilities to engage in those activities in face of the pressures of pacing concerns. This is consistent with prior research (e.g., Brophy et al., 2008; Diefes-Dux, 2004; Johnson et al., 2017; Stohlmann et al., 2011; Stinson et al., 2009), in which teachers express concerns about pacing, cutting content, and what to emphasize when students struggled, especially when enacting unfamiliar disciplines. Even teachers with unique disciplinary experience and knowledge of the STEM+CS curriculum may need help integrating across familiar disciplines (i.e., science and mathematics) and unfamiliar disciplines (i.e., engineering and computer science).

Curriculum developers should consider teachers' prior experiences and knowledge and the challenges they may encounter when integrating unfamiliar disciplines. They need to support teachers' knowledge about how concepts and practices will progress throughout an interdisciplinary project so that students are able to understand and successfully engage in activities across disciplines. Further research could consider how teachers recognize other challenges teachers face implementing interdisciplinary curricula, particularly engineering or computer science disciplines, with which they are typically less familiar.

Teachers also reflected on their self-efficacy in enacting the STEM+CS project (Muijs & Reynolds, 2002), reporting that they struggled with the broader, interdisciplinary nature of the curriculum in terms of teaching disciplines that they were unfamiliar with or content that was different from their typical science content. This is particularly important as results indicated that teachers adapted interdisciplinary activities when they felt they had ample experience to do so, including when they reported positively affecting student engagement by supporting students to use ratios to model the science phenomenon of absorption. Teachers struggled more when implementing the less familiar disciplines of engineering and computer science. These examples of modifying the project to support student engagement demonstrated that the teachers could adapt the curriculum, but they may need additional support (e.g., Alfieri et al., 2015), especially in new, interdisciplinary contexts.

Limitations and Future Research

The limitations of the present study provide several avenues for future research. First, data sources included transcripts of whole class discussion, the Teacher's Guide, and interviews and surveys. Future research should seek to understand how other supports for integration (e.g., student workbooks, small group discussions, previous lessons) promote STEM+CS integration.

Second, although there were many instances of integration, when we categorized the instances by disciplinary type in each lesson, several categories only had a few instances. Thus, it was difficult to draw conclusions about *how* each instance was implicit vs. explicit or added vs. planned. Future research could further consider the ways that different types of integration may be treated differently within the framework to help support teachers to equitably include disciplinary integration.

Third, while the two classes were different (i.e., general vs inclusive) and the teachers taught the inclusive class second, we chose to combine vs compare the instances of verbal support for integration for the two classes. Future research could consider how the classroom context (i.e., compare general or inclusive) might affect how teachers implement verbal supports for interdisciplinary integration in lessons focused on different disciplines.

Fourth, focusing on the implementation of a STEM+CS project by two elementary teachers with backgrounds that include science content knowledge means that results may not be generalizable to elementary teachers who do not have domain expertise in science. Further research could explore the verbal supports and beliefs of elementary teachers of various levels of domain expertise for different disciplines implementing NGSS-aligned, STEM+CS curricula.

Finally, we focused on what the teachers did in classroom practice rather than directly measuring teacher knowledge. Specifically, we operationalized added verbal support of interdisciplinary integration as an indication of a teacher's prior knowledge. Thus, there is a need for further research to understand the knowledge that teachers draw upon in implementing interdisciplinary STEM+CS projects.

Conclusions

Prior research highlights challenges teachers face when trying to teach ambitious, interdisciplinary STEM+CS learning (e.g., Alfieri et al., 2015) and proposes investigation into the curricular and teacher supports necessary for students to engage in highly contextualized and interdisciplinary instruction (e.g., Carlson et al., 2014). Specifically, elementary teachers are expected to engage students in interdisciplinary work, but little research has been conducted on how teachers manage to integrate different disciplines in one classroom. This study begins to fill this gap in knowledge in interdisciplinary learning within elementary science classrooms by providing a holistic picture of how teachers verbally support interdisciplinary curricula when provided with educative curricular supports.

Our results indicate verbal support of interdisciplinary integration can be explicit or implicit, planned in the educative materials or added in-the-moment. Importantly, teachers used their classroom knowledge and beliefs to make instructional decisions. Such work is important to understanding support needed for teachers to integrate interdisciplinary practices in elementary science classrooms. This work may inform future research on the kinds of supports, educative materials, and professional development that both in-service and pre-service elementary teachers need to guide teaching of interdisciplinary STEM+CS activities, integrate science, engineering, mathematics, and computer science content and practices, and move toward providing STEM+CS learning opportunities for all students.

Our goal is to support the integration of STEM+CS disciplines in elementary settings such that students do not engage in disciplinary practices separately but rather use practices across disciplines in service of each other, and that teachers are able to make connections between these disciplines through verbal supports. Future work is important to understanding needs for curricular and professional development to support teachers to both understand the epistemologies of these disciplines as well as how to support teachers to integrate science, engineering, mathematics, and computer science practices in elementary science classrooms.

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Appendix

Daily Survey and Interview Questions

(1) What do you feel like students were successful with today?
(2) What do you feel like students struggled with today?
(3) What did you feel confident about in your teaching today?
(4) What did you struggle with in your teaching today?
(5) What changes did you make to today's lesson to support students' learning?
(6) Was there anything that came up in today's lesson that you felt like you could have used some additional Professional Development to prepare for?