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Reading and Engineering: Elementary Students' Co-Application of Comprehension Strategies and Engineering Design Processes

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Abstract

For decades, researchers have asserted that K–12 teachers should embed reading comprehension instruction within each academic discipline, including "technical subjects" such as engineering. Recently, this assertion has become a source of controversy among researchers and practitioners who believe that time spent on teaching reading comprehension strategies may detract from time spent on more authentic activities such as engineering design. The purpose of this exploratory study was to investigate whether and how elementary students' applications of comprehension strategies overlapped with their application of engineering design processes. The authors provided comprehension strategy instruction to 57 third- and fifth-grade students as they read texts describing problems that could be solved through engineering. The authors used constant comparative methods to analyze students' comments from small-group and whole-class discussions about the texts. A former reading teacher with a PhD in literacy education identified students' application of reading comprehension strategies, while a former engineer with a PhD in engineering education identified their application of engineering design processes. The analysis indicated that 80.5% of comments that were coded as "comprehension strategy" were also coded as "engineering design process." Particular comprehension strategies tended to co-occur with particular engineering design processes. This study challenges the assumption that time spent in applying comprehension strategies detracts from time spent in learning engineering design. Elementary students' application of comprehension strategies occurred in conjunction with their application of engineering design processes, suggesting that comprehension strategy instruction and engineering design instruction can be conceptualized as complementary rather than competing.

Keywords: engineering education, literacy instruction, engineering design

In 1925, William Gray famously stated that every teacher is a teacher of reading (Moore, Readence, & Rickleman, 1983). He asserted that reading is necessary to learning in every academic discipline, and consequently all K–12 teachers are responsible for providing comprehension instruction on texts. Since that time, scores of books and articles have addressed the topic of content area literacy instruction, culminating in the publication of the national *Common Core State Standards* (National Governors Association Center for Best Practices and Council of Chief State School Officers, 2010), which affirmed that teachers in "scientific and technical subjects" should provide comprehension instruction within their respective disciplines. Numerous researchers (Alvermann, Swafford, & Montero, 2003; Shanahan & Shanahan, 2014) have asserted that this type of embedded comprehension instruction should start within each academic discipline while students are still in elementary school. In other words, comprehension instruction should not be reserved for elementary teachers' daily literacy blocks, or time set aside for reading and writing, but instead it should also occur as students engage in tasks such as engineering design.

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Although reading instruction is not enacted in the same way across grade levels or content areas, comprehension strategy instruction (CSI) has been recommended as a core component of reading instruction across grade levels and subjects (Block & Pressley, 2002; Collin, 2014; Duke, Pearson, Strachan, & Billman, 2011). Under a gradual release model (Pearson & Gallagher, 1983; cf. Buehl, 2011), teachers provide CSI by "thinking aloud" as they read texts. These think-alouds include the use of comprehension strategies, such as predicting, inferring, visualizing, asking questions, determining the main ideas and summarizing, or making connections. Students then practice these strategies in small groups and eventually learn to use them independently across a variety of texts. CSI often includes structured small-group, student-led discussions during which verbal or written prompts guide students to apply comprehension strategies while they discuss texts (Palinscar & Brown, 1984). Comprehension strategies feature prominently in the most popular reading programs across the United States (Dewitz, Jones, & Leahy, 2009).

Despite the pervasiveness of CSI, several scholars (e.g., Conley, 2008; Fang & Coatoam, 2013; Gillis, 2014; Moje, 2008) have critiqued this seeming "one-size-fits-all" approach to reading instruction, claiming that teachers should instead focus on the cognitive, communicative, and material practices that are specific to each discipline, rather than on generic comprehension strategies that can be applied across disciplines. In the discipline of engineering, a defining practice is design, which includes developing "concepts for devices, systems, or processes" that meet a set of criteria and constraints (Dym, Agogino, Eris, Frey, & Leifer, 2005). In order to achieve viable designs, engineers enact a series of design processes (Atman et al., 2007). Though these processes have been defined in different ways (Mehalik & Schunn, 2006), they typically include defining the problem, developing and evaluating solutions, and realizing solutions (Atman et al., 2007).

In sum, theorists and researchers have presented a seeming dichotomy between teaching generic comprehension strategies and teaching discipline-specific practices (Brozo, Moorman, Meyer, & Stewart, 2013), such as engineering design processes. To investigate whether this dichotomy appeared in the discipline of engineering, we sought to determine whether and how students' application of comprehension strategies shared common ground with their application of engineering design processes. To this end, we conducted an exploratory, qualitative study with 57 elementary students. Throughout eight monthly instructional units, we provided traditional CSI using texts containing problems that could be solved through engineering. We analyzed students' comments in relation to these texts in order to answer the following research question: How does students' application of comprehension strategies overlap with their application of engineering design processes?

Related Literature

We situate this study in the context of the larger debate between proponents of content area literacy and proponents of disciplinary literacy (Brozo et al., 2013). Proponents of content area literacy (e.g., Fagella-Luby, Graner, Deschler, & Drew, 2012; Heller, 2010) have asserted that students should receive instruction on comprehension strategies across academic disciplines. One end goal of this type of instruction is to develop students' ability to learn from texts. In contrast, proponents of disciplinary literacy (e.g., Moje, 2008; Shanahan & Shanahan, 2008) have asserted that discipline-specific practices, and not generic comprehension strategies, should be foregrounded in teachers' instruction. One end goal of this second type of literacy instruction is to use the creation and production of texts to build students' proficiency with discipline-specific practices, such as engineering design.

Although the dichotomy between content area literacy and disciplinary literacy remains prevalent in the literature (e.g., Fang & Coatam, 2013; Shanahan, 2012), several scholars (e.g., Brozo et al., 2013) have questioned the so-called "literacy-content divide," arguing instead that content area literacy instruction and disciplinary literacy instruction are complementary rather than competing approaches. According to this latter body of thought, generic comprehension strategies—such as inferring, predicting, and summarizing—can build students' proficiency with authentic disciplinary practices, such as scientific inquiry, mathematical problem solving, and (presumably) engineering design. Thus, according to this third school of thought, the learning of comprehension strategies meets both goals of building more strategic readers and greater proficiency with disciplinary practices.

In accordance with this assumption, several scholars (Friedland, McMillen, & del Prado Hill, 2011; Pearson, Moje, & Greenleaf, 2010) have identified common ground between the practices of strategic readers and the practices of scientists and mathematicians. These scholars have argued that, because disciplinary practices and the practices of proficient readers are similar, teaching comprehension strategies can support scientific inquiry and mathematical problem solving. Although scholars have identified points of intersection between comprehension strategies and disciplinary activity in science and mathematics, little research has identified common ground between comprehension strategies and engineering design processes. This study therefore fills a gap in the research literature by identifying points of overlap between the two domains. The following section outlines research literature in which scholars identify similar practices between disciplinary activity and comprehension strategies. This section then concludes with a brief discussion on research of reading instruction in the discipline of engineering.

Comprehension Strategies and Scientific Inquiry

Several scholars (Greenleaf et al., 2011; Pearson et al., 2010; Wilson & Chavez, 2014) have outlined similarities between strategic reading and scientific inquiry. For instance, strategic readers set a purpose prior to reading texts, and this purpose helps them to identify relevant information. Similarly, scientists set purposes prior to planning experiments and use these purposes to distinguish between relevant findings and noise in their results (e.g., Lynch & Woolgar, 1990). Readers make inferences by drawing from their background knowledge and available textual evidence, while scientists make inferences by drawing from previous knowledge in the field and from physical evidence and observations (Yager, 2004). In both reading and science, practitioners often make conjectures based on incomplete information. Both scientists and readers use available evidence, whether textual or physical, to support claims, and they both ask questions to clarify ambiguities (Alvermann, 2004).

In recognition of these similarities, several scholars (e.g., Hand & Prain, 2006; Wilson, 2008) have argued that comprehension strategies and scientific inquiry are not two separate entities; on the contrary, many of the practices in one domain complement, reinforce, and overlap with the other. In acknowledgment of these complementary processes, Hand and Prain (2006) critiqued previous research (e.g., Saul, 2004) for assuming that literacy and science are two separate domains that require "border crossings." They asserted that the practices inherent to reading and science often converge, and consequently teachers who build students' literacy skills as they relate to scientific texts also build students' capacity to engage in scientific practices.

Comprehension Strategies and Mathematical Problem Solving

Scholars (e.g., Fogelberg et al., 2008; Friedland et al., 2011) have likewise identified points of overlap between comprehension strategies and mathematical problem solving. For instance, visualizing is both a reading comprehension strategy and a strategy for solving mathematical problems as students draw images throughout the reasoning process (Kresse, 1994). The comprehension strategy of predicting and verifying predictions has long been recommended as a problem-solving strategy in mathematics (Siegel & Borasi, 1992). Similarly, the comprehension strategy of summarizing often solidifies students' understandings of mathematical concepts (Wilson & Chavez, 2014). Practitioners of mathematics ask questions—such as "Does this solution make sense?"—while strategic readers likewise monitor their comprehension and ask questions to clarify their understandings (Ehlinger & Pritchard, 1994).

In many cases, literacy practitioners may designate a practice as the application of comprehension strategies, while mathematics practitioners would designate the same practice as the application of problem-solving strategies (Draper & Siebert, 2004; Phillips, Bardsley, Bach, & Gibb-Brown, 2009). This assertion is supported by the review of Friedland et al. (2011) of the literature on literacy instruction in mathematics classrooms. Their annotated bibliography found 21 studies that addressed reading comprehension instruction in the mathematics classroom as a means for helping students achieve national mathematics standards. Based on their analysis of this literature, the authors concluded that mathematics educators used Polya's (1945) famous problem-solving plan to describe problem-solving processes, while literacy educators used comprehension strategies to describe the same problem-solving processes. In other words, they argued that mathematical problem solving and comprehension strategies often entail similar processes, even though practitioners in different disciplines use different sets of vocabulary to describe those processes. By implication, they argued that mathematical problem solving and comprehension strategies are not divergent or competing practices, but that comprehension instruction can support students' mathematical problem solving.

Comprehension Strategies and Engineering Design

A large body of literature has identified points of convergence between mathematical problem solving and comprehension strategies, and between scientific inquiry and comprehension strategies, but fewer studies have addressed comprehension strategies in the context of engineering design. Many studies related to reading instruction in engineering (Cunningham, 2015; Milto et al., in press) have emphasized text selection. These studies concluded that certain types of children's literature—such as fictional texts with problems that can be solved through engineering—provide a context-rich, high-interest platform from which students can begin to engage in engineering design. For instance, McCormick and Hammer (2014) and McCormick and Hynes (2012) argued that children's literature can provide students with engaging, ill-structured engineering design challenges. Their close analyses of youths' discussion of literature illustrated that youths engaged in complex forms of engineering design thinking, such as framing an ill-defined problem and identifying implicit constraints, as they sought to solve fictional characters' problems.

A few studies (e.g., Rogers et al., 2014; Tank, Moore, & Pettis, 2013) have demonstrated how CSI can be integrated with engineering design for elementary students. These studies found that students were motivated to comprehend challenging texts when they knew that they would design solutions for the characters. Authors of practitioner-oriented articles (Lacivita, 2006; Loveland, 2014; Wilson-Lopez & Gregory, 2015a) have likewise outlined how CSI can be integrated with engineering design. For instance, Loveland (2014) asserted that the application of comprehension strategies can support students' comprehension of relevant information in textbooks. Similarly, our previous work (Wilson, Smith, & Householder, 2014) indicated that high school students who applied comprehension strategies while reading their clients' problem statements understood the scope of the problem more fully than students who did not apply comprehension strategies while reading their clients' problem statements.

Collectively, these articles suggest CSI can support students' understandings of clients' problems and their understandings of relevant scientific information needed to solve those problems. These articles also suggest that engineering design challenges provide a motivating and engaging purpose for reading a variety of texts. However, we were unable to locate studies that explained how comprehension strategies and engineering design processes might work in tandem. The purpose of this study was therefore to identify points of overlap between comprehension strategies and engineering design processes. In the related fields of science and mathematics, scholars have argued that the identification of common ground between STEM (science, technology, engineering, and mathematics) practices and literacy practices provides a theoretical and empirical justification for providing literacy instruction in STEM contexts. Informed by this literature, we wanted to identify whether literacy practices—in this case, the application of comprehension strategies while reading texts that introduced engineering challenges—shared common ground with engineering practices—in this case, the application of engineering design processes.

Context of the Study

We conducted this study in a public elementary school located in a suburban region of the western United States. School records identified 90% of students as White/non-Hispanic, while another 8% were identified as Hispanic, and the remaining students were identified as Asian, Black, or multi-racial. Approximately 37% of students at the school received free and reduced lunch. From this school, we selected one third-grade classroom and one fifth-grade classroom for participation in this study for two reasons. First, the teachers were interested in integrating engineering into their instruction. Second, their existing literacy blocks, or time set aside for reading and writing instruction, focused heavily on CSI, rather than on other aspects of reading instruction such as phonemic awareness and phonics, which are emphasized more heavily in younger grades (International Reading Association, 1998). In all, 57 students participated in this study.

The first author—a former reading teacher with a PhD in literacy education (hereafter referred to as *the literacy specialist*)—co-taught eight monthly units with the second author—a former engineer with a PhD in engineering education (hereafter referred to as *the engineer*). Each unit centered around a different engineering design challenge. Table 1 provides a summary of the challenges that the students sought to solve and the texts that introduced those challenges. Each monthly unit followed the same six-step sequence. First, the students participated in CSI for one 50-minute period. During this period, they read a fictional or informational text that introduced them to a problem that could be solved through engineering. Second, students participated in demonstrations that illustrated scientific and mathematical concepts related to each challenge, such as volume for the solar oven challenge and circuits for the lighthouse challenge. Third, where applicable, they tested different possible solution elements for their designs. For instance, during the water filter challenge, they tested how well different materials (coffee filters, sand) filtered dirt and coffee from water.

Fourth, they drew labeled images of their proposed designs in their Engineers' Notebooks, and they wrote brief explanations regarding why they thought their proposed design would work using evidence from the physical tests, using the scientific and mathematical concepts they had learned, and/or using evidence from the initial text that introduced the challenge to them. Fifth, they constructed and tested a physical prototype of a complete design with the help of undergraduate engineering students who were invited to work with the elementary students. Where possible, after the elementary students tested their initial prototypes, they redesigned their prototypes in consultation with the undergraduate students. Lastly, the elementary students wrote a reflection in their Engineers' Notebooks regarding how well their designs worked and what they would do differently the next time if they were to build and test another prototype. During this sixth and final activity, we led whole-class discussions in which students shared the reflections that they wrote in their Engineers' Notebooks.

This unit included a variety of opportunities to read, write, and discuss engineering ideas, but for the purpose of this study, we focus only on the first part of the instructional sequence. Specifically, data for this study were taken from the first 50-minute literacy blocks in which students actively applied a variety of comprehension strategies as they read texts that introduced them to engineering design challenges. We focused on this first instructional block because it was the only block in which we explicitly targeted the reading of texts, and we wanted to identify how elementary students' application of comprehension strategies overlapped with their application of engineering design processes. In other studies (e.g., Wilson-Lopez & Gregory, 2015b), we focus more on students' learning in relation to other aspects of the instructional sequence. In the following section, we describe the types of activities that occurred during this first instructional block, which focused on CSI, in each monthly unit.

Table 1.
Summary of monthly literacy-infused engineering units.

Text and Description of Problem Faced by Character	Engineering Challenge
The Boy Who Harnessed the Wind (Kambkwamba & Mealer, 2012). William Kamkwamba's village in Malawi is facing a drought, so the 14-year-old boy uses available materials to build a windmill that powers a water pump.	Students engineer a model windmill that can lift as many marbles as possible when an electric fan blows on it.
Candy Bomber: The Story of the Berlin Airlift's "Chocolate Pilot" (O'Tunnell, 2010). Pilot Lt. Gail Halvorsen wants to safely deliver candy to children who live in Berlin, which has been war-ravaged and blockaded immediately following World War II.	Students engineer a parachute that can drop a fun-sized candy bar to the ground at a rate of five feet per second or slower.
The 5,000 Year Old Puzzle: Solving a Mystery of Ancient Egypt (Logan, 2002). Archeologist George Reisner has uncovered an Egyptian tomb in 1924, but his team needs a safe way to illuminate it. They position a large nickel plate in the entryway to reflect light from the sun into the burial chamber.	Students engineer a lighting system by positioning mirrors inside a cardboard box, so that a flashlight shined into the box can illuminate different hieroglyphs posted on the sides of the box.
Document 526: Post Implementation Report for Masaka District, Uganda, Byana Mary Hill Orphanage (Engineers Without Borders USA, 2010). The children in Byana Mary Hill Orphanage in Masaka, Uganda need access to useable water. To partially address this problem, an Engineers Without Borders team installed a roof rainwater catchment system.	Students engineer a water filter that visibly removes dirt and coffee from water.
Abbie Against the Storm: The True Story of a Young Heroine and a Lighthouse (Vaughan, 1999). In the midst of a storm, young Abbie Burgess must illuminate the rocky shore when her father, the lighthouse keeper, is away. *Lighthouse Cat* (Stainton, 2004). The lights in the lighthouse are extinguished in the middle of a storm, threatening the ships near the shore.	Students engineer a lighthouse through designing an electrical circuit and placing the resultant light on top of a structure they design. The lighthouse must illuminate mystery objects placed 1.5 meters away in a dark room.
S Is for S'mores: A Camping Alphabet (James, 2007). In our modified version of this tale, a family wants to roast marshmallows over the fire to make S'mores, but the firewood is damp from a rainstorm that happened the night before. The family must find an alternative way to melt the marshmallows.	Students engineer a solar oven that melts marshmallows as quickly as possible when placed under a heating lamp.
Oil Spill! (Berger, 1994). After the Exxon Valdez spilled millions of gallons into the ocean, environmental engineers must first contain the spill and then clean it up. *After the Spill: The Exxon Valdez Disaster, Then and Now* (Markle, 1999). Markle describes the environmental and economic impacts of the spill.	Students engineer a way to prevent colored vegetable oil from spreading in water. They then engineer a way to soak up as much oil as possible from the water.
The Brooklyn Bridge (Mann, 1996). John Roebling must find a way to help people carry heavy loads across the East River from New York to Brooklyn. *Brooklyn Bridge* (Curlee, 2001). In addition to describing John Roebling's dilemma, Curlee details the difficulties that construction workers faced in actually building the bridge, such as the difficulties associated with working in caissons under river water.	Students engineer a three-foot-long bridge that can safely hold more weight than a three-foot-long "beam bridge" made of the same material.

Example of Comprehension Strategy Instruction

Students began each monthly unit by reading texts with problems that could be solved through engineering. Although the third- and fifth-grade students both addressed the same engineering design challenge each month, we sought to choose age-appropriate texts for the students. For instance, according to the Lexile framework for reading (MetaMetrics, 2015), *Candy Bomber* (O'Tunnell, 2010) would likely be too difficult for third-graders but is appropriate for fifth-graders. Consequently, the fifth-grade students read several excerpts from this biography, but we rewrote these excerpts by simplifying complex sentences and vocabulary for the third-graders. We (the first and second authors) co-taught the third- and fifth-grade classes by providing CSI on the texts that we had selected for each unit. The two classes were not combined during the days that we provided CSI, and thus we taught each third- and fifth-grade class separately.

During these initial class periods, we conducted think-alouds, in which we modeled for students how to apply different comprehension strategies as we read aloud from the texts (Block & Israel, 2004; Wilson & Chavez, 2014). These comprehension strategies included predicting, inferring, visualizing, asking questions, summarizing, and making connections (Block & Pressley, 2002). Students then practiced these strategies, often through independently annotating copies of their own texts and through verbally discussing their annotations in small groups (Fisher & Frey, 2014; Palinscar & Brown, 1984). Following these individual annotations and small-group discussions, we returned to whole-class discussions in which students shared the insights they gained through reading. This type of reading instruction aligns with recommendations from previous research (Duke et al., 2011; Pearson & Gallagher, 1983), which suggest a gradual release approach to CSI in which teachers model individual comprehension strategies and then students practice these strategies both in small groups and independently, in the context of a discussion-rich environment.

For example, in the unit that addressed the water filter challenge for fifth-grade students, we began by showing photographs and maps of an orphanage in Uganda that was serviced by a local chapter of Engineers Without Borders (EWB). To teach the comprehension strategy of inferring, we first defined what inferring was, and we modeled for students how to make inferences (cf. Duke et al., 2011). For instance, we inferred that it must be hot at the boarding school because the map showed it was near the equator. Students then read sections of a simplified report written by EWB (2010), which described how people in the orphanage collected rainwater from rooftops by channeling it into a tank. Students individually annotated their own texts by writing inferences in the margins, but they were also encouraged to use other comprehension strategies they had learned throughout the year, such as asking questions or predicting. After students had read a brief section and shared their annotations in small groups, we stopped and discussed their annotations as a whole class. They individually annotated the next section of the text, shared their annotations in groups, and we again stopped to discuss their annotations as a whole class.

As students shared their annotations, the class collectively defined the problem presented in EWB's report. Students identified that they needed to filter the dirt from the water in the tank. They also noted that people at the orphanage did not have a lot of money, and thus they needed to use inexpensive materials for the water filters. They also inferred that people in the orphanage might not have the same ready access to materials when compared to people in the elementary students' suburban region of the USA. After students had identified potential inexpensive filters that would be available in the region (e.g., sand) or filters that could be easily brought by EWB (e.g., coffee filters), we later brought these materials to class so that the students could test them prior to making their own designs. Throughout the process, students recorded initial ideas in their Engineers' Notebooks, even before they were formally asked to draw labeled pictures of their proposed designs. For instance, during this unit, several students wrote criteria that their design must meet (must filter dirt, must be inexpensive) in their notebooks.

Method

We drew from methods associated with cooperative inquiry (Reason, 1994) to conduct an exploratory qualitative study in two elementary classrooms over the duration of one school year (approximately nine months). Draper and Siebert (2004) recommended cooperative inquiry for situations in which co-researchers come from different disciplinary backgrounds. One primary purpose of cooperative inquiry involves the active interchange of ideas as each researcher uses his or her specific disciplinary lens in order to describe or explain a phenomenon. In this case, the first author (a former reading teacher) used constructs and terminology from the field of reading comprehension research to categorize the elementary students' comments, whereas the second author (a former engineer) used constructs and terminology from the field of engineering education research to categorize the elementary students' comments. In cooperative inquiry, "full reciprocity" is sought as co-researchers rigorously value and consider both sets of perspectives (Reason, 1994, p. 326). The following section explains how we used constructs from reading comprehension research and from engineering education research to identify points of overlap between students' application of comprehension strategies and engineering design processes.

Data Collection

This study is based on two sources of data: student comments from whole-class discussions and student comments from small-group discussions. We audio-recorded each 50-minute class period in which students read and discussed texts that introduced engineering design challenges. Before each period, we placed audio-recorders in two locations: in the front of the classroom so that we could audio-record whole-class discussions regarding the text, and beside individual groups (comprised of three to four students each) so that we could capture their small-group discussions of the texts. Although we implemented eight engineering units in the third-grade classroom and the fifth-grade classroom, we faced scheduling difficulties with the third-grade teacher and consequently the students did not read an introductory text and participate in CSI during one instructional unit. Thus, we collected audio-recordings from approximately 400 (50 minutes $\times$ 8 instructional units) total minutes of classroom instruction from the fifth-graders and audio-recordings from approximately 350 (50 minutes $\times$ 7 instructional units) total minutes of classroom instruction from the third-graders.

During these instructional blocks in which students read and discussed the texts, we collected three sources of data. First, we collected and transcribed audio-recordings of whole-class instruction, including student discussions surrounding the texts. Second, we collected students' Engineers' Notebooks and other written assignments, such as student annotations of texts. Students used these written products to prompt their small-group discussions. For instance, after students annotated their texts, they were asked to share their annotations in their groups (cf., Palinscar & Brown, 1984). As students were holding small-group discussions, the researchers also walked around to each group, pointed to different annotations or writings, and asked students to "tell us more about this" while pointing to a particular line or section of student work that was unclear. These researcher prompts led to further small-group discussion. For instance, one student wrote an inference that the word *renewable* meant "it will come back." When the researcher asked the student to tell her more about the word renewable, her group chimed in to help her further define the meaning of the word renewable. This exchange was captured on audio-recording and transcribed. For our third data source, we collected and transcribed audio-recordings from small-group discussions.

In the end, we did not formally analyze the second data source (the students' written products) for two reasons. First, many elementary students more fully articulate their thinking in oral speech as opposed to writing (Berland & McNeill, 2010). Second, because we asked students to verbally share the content of their writings, we concluded that coding both the writing and the verbal speech would lead to an inflated count. For instance, if a student asked a question in her Engineer's Notebook or in the margins of a text, and then she verbally shared that same question with her group, we believed that question should only be counted and coded once rather than twice. Thus, our research followed previous methodologies (e.g., Wilson-Lopez, Mejia, Hasbún, & Kasun, 2016) in which researchers used written and visual work to prompt verbal comments, but the written work itself was not formally analyzed.

Data Analysis

We analyzed the data using a modified form of constant comparative analysis (CCA; Corbin & Strauss, 2014). CCA has previously been associated with grounded theory, an approach to research in which codes are inductively developed from data. In critiquing this method, Smagorinsky (2008) argued that researchers' work is usually informed by previous studies, and thus predetermined codes from prior studies can initially be applied to new data sets. This application of predetermined codes does not necessarily preclude inductive coding, however. Instead, Smagorinsky argued that researchers can modify previous codes, exclude certain codes, or expand the possible set of codes as they discuss the ways in which codes from previous studies map onto the data from their particular study.

Working under this approach, the literacy specialist created a list of *a priori* codes that previous researchers (e.g., Roser & Keehn, 2002) used to categorize students' applications of comprehension strategies, while the engineer created a list of *a priori* codes that previous researchers (e.g., Atman et al., 2007) used to categorize students' applications of engineering design processes. We read through randomly selected data excerpts and discussed the ways in which these pre-existing codes mapped onto the data from this study. We then modified the codes so that they more accurately described the data from this study.

For instance, previous research (e.g., McKeown, Beck, & Blake, 2009) defined predicting in part as identifying what a character *will* do, but we found that several of the students offered advice to a character on what he or she *should* do. Because these comments still forecasted potential futures based on students' understandings of past sections of the text, we identified these suggestions to the character as a form of predicting. As in this example, we noted other patterns we saw in the data, and we modified *a priori* codes to describe the patterns we noticed in this data set. Tables 2 and 3 include the final codes that we developed to categorize students' application of comprehension strategies and engineering design processes. This table also includes examples of data points to which we assigned each code.

After we had developed this set of codes, the literacy specialist analyzed the entire data set using the codes related to comprehension strategies, while the engineer analyzed the entire data set using the codes related to engineering design processes. Throughout the coding process, we treated each conversational turn—delineated by when a new person spoke—as one data point, and we often assigned multiple codes to individual data points. For instance, one student said, "If the wood's rotten from too much wet on it, then you might want to do something else, like brick." The engineer coded this statement as both evaluating solutions (evaluate the wood as an unsatisfactory solution element) and generating ideas (offering an alternative to wood).

We sought to establish that the codes were credible (Lincoln & Guba, 1985), or that the codes reasonably fitted the data, and that external researchers could categorize the same data points in a similar way. Although some qualitative researchers and methodologists (Boyatzis, 1998; DeCuir-Gunby, Marshall, & McCulloch, 2011; Krippendorff, 2009) establish credibility through intercoder agreement, other qualitative researchers and methodologists (e.g., Harry, Sturges, & Klinger, 2005; Kvale & Brinkman, 2009; Sandelowski & Barroso, 2007; Smagorinsky, 2008) establish credibility through mutual discussion until researchers reach consensus on the codes that should be assigned to each data point. Many qualitative methodologists (Freeman, deMarrais, Preissle, Roulston, & St. Pierre, 2007; Saldaña, 2012) have asserted that both methods of establishing credibility are valid, and both have been used in previous qualitative studies related to literacy or engineering (e.g., Roth, 1997; Smagorinsky & O'Donell-Allen, 1998; Smagorinsky, Wilson, & Moore, 2011; Wilson-Lopez et al., 2016). Because this study was conducted under the umbrella of collaborative inquiry, in which each researcher's viewpoint was rigorously incorporated at each stage of the process, we opted to establish reliability through the latter method of mutual discussion and consensus. Accordingly, the literacy specialist and the engineer read through each other's codes of the data, and we discussed the data until we agreed upon the assignment of each code.

Table 2.
Comprehension strategy codes assigned to students' verbal comments.

Definition of Code	Example of Data Excerpt Given that Code
Ask a question: Students clarify parts of texts that are confusing to them or ask for information beyond what is explicitly stated in the text.	Where is the hole [in the water tank]? At the top?
Infer: Students draw from their background knowledge or information in the text to arrive at a tentative conclusion that is not explicitly stated in the text.	I think it [the lighthouse] needs to be tall. If it was just this tall [puts one hand about a foot above the floor], I don't think many ships would be seeing it because if it was that tall then no one could really see it because maybe the rocks would be taller than it.
Make connection: Students compare or contrast an event in the text they are reading to an event from their own lives or from another text they have read.	Sometimes in the summer I'll wear just a t-shirt, but anyway, when I wear a white t-shirt in the summer, I'll still get warm, but not as warm as if I was wearing a black t-shirt or this jacket. So…[for the solar oven] black paint will absorb, and heat goes in.
Predict: Students use textual constraints to forecast what a character will or should do in a narrative and/or to predict future outcomes or events.	There will probably be booby traps. The Egyptians put booby traps in there [the tomb] because they know people are going to try to rob it.
Summarize: Students restate the major events or concepts presented in a text in their own words.	We use them [fossil fuels] for all kinds of stuff like making cars work, and machines work, and you can even use them in a stove.
Visualize: Students construct mental images of events, objects, or other phenomena described within a text or indicated by a text.	[Pointing to various parts of a picture she had drawn to indicate what she thinks the character's final product should look like]. There should be strings up here, and strings down here. There will be a basket. It will be bigger than this.

Table 3.
Engineering design process codes assigned to students' verbal comments.

Define problem: Students identify a need or problem faced by a character; they identify criteria or constraints needed for a successful solution; or they gather information regarding the problem.	Does the water have to go through [under the bridge]? Does a bridge have to be across the water? How heavy is the candy going to be?
Generate ideas: Students brainstorm potential solution elements or solutions to the problem.	They [the archeologists] could use something that when they dug down, light comes in. They could get a mirror and go right there and shine light into it [the tomb].
Evaluate solutions: Students pass judgment on the workability of a solution or solution element.	So wouldn't a small box not be good [for a solar oven] because wouldn't it get overheated and too hot, because there's too much heat in it, cause it's smaller?
Model: Students offer details, such as measurements, regarding how to build the solution to the problem, or parts of the solution to the problem.	The bridge will be two feet high right here and I don't know how long.
Communicate solutions: Students communicate elements of their final designs to others.	The heat lamp is right here [points to drawing], so it comes down. The light goes in, and heats up the aluminum foil. This is a pizza box [points to drawing].

To further establish trustworthiness in our data analysis methods, we invited Vic, the third author, to conduct a data audit (Lincoln & Guba, 1985). He read through 10% of randomly selected transcripts and confirmed that all codes related to engineering design processes and comprehension strategies accurately reflected the phenomena represented in the transcripts. A former elementary teacher, Vic specializes in both STEM instruction as well as literacy instruction. Thus, his expertise enabled him to evaluate the literacy specialist's and engineer's use of literacy and engineering codes as they applied to an elementary context. Finally, we sought to establish trustworthiness in data analysis through thick description (Freeman et al., 2007; Geertz, 1973; Lincoln & Guba, 1985). In the findings section below, we provide numerous examples of student comments and we explain why we assigned particular codes to each comment. In this way, we sought to provide readers with enough information to determine for themselves how our codes mapped onto the data.

After the first two authors had reached consensus regarding the codes that had been assigned to each data point, and after the third author conducted a data audit, we conducted frequency counts to identify points of overlap between the two sets of codes (see Table 4). Because we focused

Table 4.
Summary of overlap between literacy and engineering codes.

	Percentage of Comments Applying the Engineering Design Process				
Comprehension Strategy	Define Problem	Generate Ideas	Evaluate Solutions	Model	Communicate Solutions
Predict (n = 399)	8.3	63.4	26.8	7.0	5.5
Infer (n = 190)	27.9	7.9	32.1	0	0
Ask Question (n = 101)	59.4	0.8	0.4	0	0
Summarize (n = 81)	49.4	3.7	13.6	0	3.6
Visualize (n = 79)	0	6.3	0	40.5	0
Connect (n = 46)	39.1	10.8	8.7	0	0

primarily on teaching comprehension strategies during the teachers' literacy blocks, we began by conducting a frequency count of each data point that had been assigned with a particular comprehension strategy code. We then determined whether data points that had been assigned with that *comprehension strategy* code also tended to be assigned with particular *engineering design process* codes. When we found that particular design processes co-occurred with particular comprehension strategies in over 25% of the data points, we discussed these co-occurrences from our perspectives as a reading teacher and as an engineer. Specifically, we described how we perceived the same phenomena using concepts from our respective fields.

For instance, we identified that 399 comments had been coded as *predicting*. We then asked: Of those 399 comments, how many of them were also coded as *defining the problem, generating ideas, evaluating solutions, modeling, or communicating solutions?* We found that 63.4% of comments that had been coded as *predicting* had also been coded as *generating ideas.* As we discussed individual data points, we found that the literacy specialist often described a given comment in terms of generating possible ideas based on "textual evidence," a term that is used often in the Common Core State Standards related to literacy (NGACBP & CCSSO, 2010). By contrast, the engineer described the same comment in terms of generating possible ideas based on "criteria and constraints," a term that is used often in standards and frameworks related to engineering (e.g., International Technology Educators Association/International Technology and Engineering Educators Association, 2007). In the findings section, we describe in more detail how we each used our distinctive bodies of expertise to analyze the same student comments using discipline-specific constructs.

Limitations

This study was conducted in an elementary school with a primarily White student body. Additional research can be conducted with more diverse groups of students in order to determine how they apply comprehension strategies in conjunction with different engineering design processes. By drawing heavily from *a priori* codes in existing research literature, we also limited the study in the sense that we did not account for how elementary students may approach engineering design or comprehension in idiosyncratic ways. Wilson-Lopez et al. (2016) have critiqued existing descriptions of engineering design processes, arguing that students from non-mainstream cultures often approach engineering design in non-canonical yet effective ways. Our reliance on these pre-existing codes did not enable us to capture perhaps "unconventional" lines of reasoning that the students employed toward both comprehension and design (cf.Hull & Rose, 1990).

Findings

In all, the elementary students made 938 comments that were coded as the application of a comprehension strategy, an engineering design process, or both. We found that 80.5% of data points that were coded as "comprehension strategy" were also coded as "engineering design process," an indication that the two domains were overlapping rather than opposing. We also found that particular comprehension strategies tended to co-occur with particular engineering design processes (see Table 4). For all instances in which we assigned more than 25% of data points with a comprehension strategy code and engineering design process code, we provide examples to illustrate how we coded the same comment using constructs from our respective disciplines (reading or engineering). All names in this section are pseudonyms, and the codes assigned to the data are italicized.

Predicting

As indicated by Table 4, the students most commonly applied the comprehension strategy of *predicting*, and 63.4% of predictions were also coded as *generating ideas.* A few examples from the data set will illustrate how this comprehension strategy co-occurred with idea generation. After the teacher had previously conducted think-alouds on predicting, which included modeling how to use textual evidence to make an educated guess about what would happen next, the third-grade students read excerpts from *The 5,000 Year Old Puzzle* (Logan, 2002). This work of historical fiction followed an archeological team who discovered Queen Hetep-heres' tomb in 1924, but it was so dark that they could not see into it. The team needed a way to light the tomb without endangering the ancient artifacts. At this point in the story, students entered a whole-class discussion in which they shared their predictions about what the archeologists would do.

The teacher, who encouraged the students to put themselves in the shoes of archeologists, began the discussion by summarizing the previous section of the text: "So you found the tomb, but the problem is it's so dark you cannot even see." One student responded with, "You could use a flashlight," while another student rejoined, "But it's 100 years back, so they haven't invented the flashlight." Students then made other predictions, such as that the team could use candles or torches, which would have been available in 1924. However, they decided that they would not use that option either, because "the tomb is really small so it could accidentally light something on fire." After deciding that the archeological team probably would not use fire-based solutions for this reason, another student suggested, "We could use something that reflects," to which another added, "Something that when they dug down, light comes in. They could get a mirror and go right there [points to illustration projected on SmartBoard] and shine light into it."

The literacy specialist coded several of these comments as *predictions* because students used information from the text to forecast what the archeological team would or should do next. For instance, a previous section of the text emphasized that the underground chamber was "tiny, and it's so full stuff that no one can enter without stepping on something" (p. 20). One student used this textual evidence to predict that, if the team did use a torch, it "could accidentally light something on fire" because the artifacts were enclosed in such a small area. Consequently, the students collectively predicted that the archeologists would or should instead use "something that reflects" as a better solution to their problem.

The engineer coded several statements—such as "You could use a flashlight" "You could use a torch," and "They could get a mirror"—as *generating ideas* because students initially began to brainstorm solutions to the characters' problem. The students used other textual evidence, such as the fact that the dig occurred in 1924, to *evaluate possible solutions*, such as the flashlight, which they did not believe would have been widely available "100 years ago." In other words, the students identified a constraint by considering what they believed to be available technology during the time period, and they accounted for this constraint when they then further *generated ideas* by offering alternative solutions that used available technologies, such as torches and mirrors.

Another example from the data set will illustrate how *predicting* co-occurred with *generating ideas.* Several third-graders discussed *Oil Spill!* (Berger, 1994), a text in which environmental engineers addressed the problem of the Exxon Valdez leaking oil into the Gulf of Alaska. The teacher began by showing illustrations in the book, and one student noted that the oil stayed on top of the water in the illustration. The observation that oil "stays on top" of water was cited several times in small-group discussions, as students made comments such as, "It doesn't mix cause it stays on top, and it just stays there, and you can kind of lift it off the water." This observation formed the basis for students' later predictions that the engineers would just "lift" the oil off of the water since it "didn't mix" with the water. For instance, one group held the following discussion:

Student 1: We could get a vacuum.
Teacher: Excellent! [to Student 2] What do you think?
Student 2: I was going to say, we could take a large container and try to scoop it up.
Student 3: If they soak up the oil, then they have to get rid of the soaked up oil […]
Student 4: Where does it go?
Teacher: Good question! Where do they put it? Are they just going to put it on the beach?
Students 1–4: No!
Student 1: Then it's going to get on the sand.
Student 2: Why don't they put it on fire?
Student 4: They could re-use that oil.

In this excerpt, the students applied the comprehension strategy of *predicting*, a strategy that is often practiced by "good readers" (Pressley, 2001), as they considered possible courses of action for the characters, which included using different means to collect the oil and either set it on fire or reuse it. They also engaged in *generating ideas*, a stage of the engineering design process that engineers practice as they devise possible solutions.

The literacy specialist identified numerous comments as *making predictions* grounded in textual evidence, while the engineer identified these same comments as *generating ideas* that are grounded in constraints. From the literacy specialist's perspective, students drew from textual evidence (the illustrations in which oil stayed on top of water; the written description of the tomb as small and crowded) to make predictions about how characters would or should act. From the engineer's perspective, students considered existing facts (e.g., scientific principles, the physical context of the problem), identified criteria and constraints (e.g., those related to availability of materials), and generated ideas for solving a problem within these parameters. We inferred that *predicting* and *generating ideas* frequently overlapped because they both entailed projecting possible future solutions based on available knowledge.

Predicting and *evaluating ideas* were also overlapping processes, though they co-occurred together to a lesser extent, as 26.8% of comments coded as *predicting* were also coded as *evaluating ideas* (see Table 1). For example, students read excerpts from *Candy Bomber* (O'Tunnell, 2010), a biography of Lt. Gail Halvorsen who sought to safely drop candy from a plane to children in blockaded Berlin in 1948. One fifth-grade student suggested that Halvorsen could tie ropes to the bottom of the plane that would extend all the way to the ground, and the children could grab candy from the ropes. Another student drew from textual evidence, such as the description of strict rationing after World War II, to *evaluate that solution* as unrealistic based on the availability of materials. She predicted that instead he would "put a parachute on the candy…with the cloths [handkerchiefs]" featured in photographs in the text. In turn, the first student conceded that her rope idea was unrealistic in the sense that there would "not be enough rope." In this example, one student *evaluated a solution* and justified her reasoning with evidence from the text.

Throughout multiple units, other students similarly evaluated their peers' predictions as realistic or unrealistic, instead offering their alternative predictions about what the character would do, based on specific evidence from visuals in the text or from the written text. For instance, one student revised his prediction that the archeologists would use a torch after considering the cramped quarters full of ancient artifacts. When viewed from the perspective of the literacy specialist, these comments demonstrated active reading, including revising predictions as new textual evidence became available (Pressley, 2001). When viewed from the perspective of the engineer, the students re-evaluated potential solutions as more information became available. Thus, we found that *making and revising predictions* and *evaluating solutions* were also co-occurring processes.

Inferring and Asking Questions

After predicting, *inferring* was the second most common comprehension strategy, followed by *asking questions.* We found that inferring and asking questions were commonly used together as part of the *problem definition* stage of the engineering design process, and consequently we describe both strategies in this section. The following example will illustrate how inferring and asking questions co-occurred with problem definition. Prior to designing a water filter, students read a simplified, truncated version of an EWB report (EWB USA, 2010). This report described an orphanage in Uganda, which needed assistance with water acquisition because the nearest well was about 500 yards away from the living quarters, requiring children to carry buckets of water uphill. Students viewed photographs of the orphanage, including the water catchment system that EWB had recently installed on roofs, which channeled rainwater into barrels. At the end of the report, students were charged with designing a water filter that could clean the water in the barrels, although throughout the report they were introduced to the problem of acquiring clean water at the orphanage in general.

Prior to reading the text, the teacher conducted a think-aloud for the students on how to apply the comprehension strategy of inferring. The students were encouraged to annotate their EWB reports with inferences, as well as other comprehension strategies they had learned throughout the year, such as asking questions and summarizing. The following excerpt is from the whole-class discussion in which the fifth-grade students were asked to share their annotations:

> Student: My inference was, is it [the water in the rain barrel] safe just for bathing? Or it's dirty, so it might not be good for drinking.
> Teacher: He thinks rainwater may be safe for bathing because you don't really drink it, but maybe it's not safe for drinking. That is an excellence inference. Lisa?
> Student: My inference is, where is the hole? At the top?
> Teacher: That's a good question. It looks like the water goes in there [points to top of the barrel in the photograph] and the water comes out at the bottom through the spigot [points to the spigot in the photograph]. Yes ma'am?
> Student: My question was, it is clean? When the rain falls on top of the roof, there could be small bugs that die on the roof and get into the can and they drink it. […]
> Teacher: Yeah, if the water's hitting the roof and going in, we don't know if it's safe to drink. Janice?
> Student: Where do they get supplies and how do they afford it?
> Student: My inference was maybe people donated the supplies.
> Student: How far away is the barrel is my question? My inference was that the well probably isn't used as much now.
> Teacher: That is a great inference. So probably if you're a kid and it's so hot, and you're carrying these heavy buckets [from the well] all day, you probably want to use the rainwater if it's closer. You probably don't want to go all the way down to the well. Nick, go ahead.
> Student: My question was, do they get enough rain to have it for everybody? […] How much water can the barrel hold?

In this excerpt, students used the comprehension strategies of inferring and asking questions, both of which are emphasized in the Common Core State Standards for literacy in the elementary grades (e.g. CCSS.ELA-Literacy. R1.3.1, CCSS.ELA-Literacy.R1.5.1). At times, they asked clarifying questions to solidify their understandings, such as when Lisa asked where the hole in the barrel was, and the teacher responded by pointing to the photograph. Duke and Pearson (2008/2009) defined clarifying questions as those whose purpose is "clarifying basic material stated in the text" (p. 108). Alvermann (2004) asserted that *asking clarifying questions* is an important comprehension strategy in the discipline of science because it enables students to stabilize their understandings of visual and written texts. Lapp, Grant, Moss, and Johnson (2013) similarly asserted that basic factual questions are vital to support elementary students' close readings of scientific texts as recommended by the CCSS.

While the literacy specialist identified Lisa's comment as the *reading comprehension strategy* of asking clarifying questions about a text, the engineer asserted that this question was a form of *problem scoping* in the sense that it enabled Lisa to clarify an aspect of the problem she still did not understand. Several scholars (e.g., Atman et al., 2007; Mentzer, Becker, & Sutton, 2015; Wilson, Householder, & Smith, 2013) have described how engineers and students of engineering ask a host of questions during the problem scoping stage. For novices especially, these questions often include clarifying questions in order to ensure they understand the clients' needs. For instance, our previous work (Wilson et al., 2014) suggested high school students who asked basic clarifying questions about a client's problem statement understood the problem more fully than high school students who did not ask these questions, and thus were able to define and address the problem rather than remaining confused throughout the entire design process. Thus, asking clarifying questions is not only a strategy for helping students understand texts, it is also a strategy for helping students understand problems, and thus can be a component of *problem scoping.*

More commonly, the students did not ask clarifying questions whose answers could be found by referring back to the EWB report, but instead they asked questions whose answers were not found in the report. Pearson and Johnson (1978; cf. Cortese, 2003; Raphael & Au, 2005) identified this type of question as a scriptually implicit question that is derived from a text but whose answer cannot be found within the text. They asserted that proficient readers often ask this type of question as they read, in addition to clarifying questions. Scriptually implicit questions relate to the information gathering component of the problem definition stage, in which engineers identify information that is still needed in order to effectively address the problem (Atman et al., 2007; Bursic & Atman, 1997). This information is often not explicitly stated in the verbal or written problem statements that clients provide to engineers; instead, engineers must go beyond given information to solve the problem (Dym & Little, 2009).

In the data excerpt above, to address the problem of water acquisition at the orphanage, students asked scriptually implicit questions in several domains as they sought to further understand (a) the dimensions of the barrel; (b) how the barrel water would be used; (c) aspects of the spatial layout of the enclosure, such as whether the rain barrel would be closer than the well; (d) regional weather conditions; and (e) the availability of materials for an institution that was obviously very poor. Although students generated these questions in the context of CSI, the engineer identified these questions as *problem definition* work in which students considered various parameters of the problem that were not explicitly stated in the text.

Oftentimes, students used inferences in conjunction with asking questions in the same conversational turn. For instance, one student inferred that rainwater was dirty, and this inference formed the basis for his question regarding whether the children only used the rainwater for bathing. A second student inferred that children would use the closer water source, and she used this inference as the basis for her question regarding whether or not the barrel of rainwater would be closer than the well. In sum, students coordinated the comprehension strategies of inferring and asking questions in an effort to develop more complete understandings of the problem. Thus, inferences not only entailed drawing conclusions that were not stated in the text, but they also served as the basis for further information gathering activity, such as when the inferences were used as the basis for further questioning.

Dym and Little (2009) asserted that engineers must often make inferences in the problem scoping stage of the engineering design process because clients rarely outline all relevant aspects of the problem. Previous research (Wilson et al., 2014) has similarly suggested that youths who make inferences while reading clients' problem statements are more likely to produce designs that meet clients' needs, as opposed to those who do not make inferences beyond what is explicitly stated in the problem. Thus, although *making inferences* about a text is a reading comprehension strategy outlined in the CCSS, the engineer identified it as a form of problem scoping as students sought to identify implicit criteria and constraints, which is an engineering design process recommended in engineering standards (e.g., ITEA/ITEEA, 2007).

In addition to identifying points of overlap between inferring and problem scoping, we also identified points of overlap between *inferring* (a reading comprehension strategy) and *evaluating solutions* (a component of the engineering design process). Several examples will illustrate how students used inferences to evaluate the characters' solutions or their own suggested solutions. One third-grader commented that Gail Halvorsen used a lot of strings in his candy-dropping parachute, "so it can hold together more, so this part [points to photograph] won't rip off." Although Halvorsen's biography did not include information about why he decided on particular solution elements, such as a certain number of strings, in this example, the student made inferences as to the reason behind different solution elements. In this case, a student evaluated one aspect of Halvorsen's design—the number of strings on the parachute—as satisfactory because that number of strings would prevent the handkerchief from ripping off of the candy.

As a second example, the third-grade students evaluated the characters' current lighthouse design as they read *Lighthouse Cat* (Stainton, 2004). One third-grader commented that the lighthouse "needs to be tall. If it was just this tall [points to lighthouse in illustration], then no one could really see it because maybe the rocks could be taller than it." In response to this comment, another student agreed that the existing lighthouse was too short: "The ocean would wash it out, and if you had windows, it would be better [than the current design without windows], but still no one could really see it." In both of these excerpts, the students used textual evidence to evaluate one solution element, height, as being unsatisfactory. In the first case, the student drew from evidence in the illustration—the height of the rocks—to justify her claim. In the second comment, the student used evidence from previous sections of the book, which indicated that tall ocean waves could crash on the island during a storm, to further justify her claim that the existing lighthouse was too short.

From the literacy specialist's perspective, the students drew from textual evidence, such as components of the story illustrations, to *make inferences*. In the case of the parachute, the student inferred the character's motivation for using a particular number of strings, whereas in the second case, the student inferred that sailors could not see the existing lighthouse because it was too short. By contrast, the engineer identified these comments as *evaluating solutions* based on the following criteria, which were not explicitly stated in the text: The people in the ships must be able to see the lighthouse, and the candy must not fall off of the parachute. As in these examples, the literacy specialist and the engineer identified points of overlap between comments that were coded as *inferring* and those that were coded as *evaluating solutions*, processes that co-occurred as students sought to draw evaluative conclusions that incorporated, but extended beyond, information explicitly stated in the text.

Summarizing

About half (49.4%) of comments that had been coded as *summarizing* (a reading comprehension strategy) were also coded as *defining the problem* (a component of the engineering design process). Several examples from the data set will illustrate how the literacy specialist and the engineer coded the same comment using these two different sets of codes. Third-grade students read *The Brooklyn Bridge* (Mann, 1996), which described how and why John Roebling designed the world-famous suspension bridge to help people cross the East River. After reading the first few pages, one third-grader summarized the text as follows: "The boat takes the people half a mile to the other side. There's horses on the boat, and there's suitcases, and hay and people…those would weigh a lot."

The literacy specialist coded this statement as *summarizing* because the student identified and paraphrased aspects of the text that he believed were important. The engineer identified this comment as *problem definition* because this statement began to clarify parameters of the problem. For instance, the student noted that the river was half a mile wide in some places, forming the basis for later estimations regarding how long the bridge should be. He also observed that the ferries carried heavy items, forming the basis for later assertions that the bridge should be able to support a lot of weight. Drawing from this summary, another student remarked that if John Roebling planned to design a bridge to span the river, "It needs to be sturdy and it needs to be long and it needs to not fall down when [carriages] go on it." In this case, the student's summary—which included paraphrasing and/or restating key ideas in a text—also entailed problem definition as the students used their summaries to identify important aspects of the problem that deserved their attention.

Other examples suggested that problem definition and summarizing were overlapping processes as well. For instance, fifth-graders read *Abbie Against the Storm* (Vaughan, 1999), a work of historical fiction. In this narrative, a young teenager ran her family's lighthouse while her father was away. The family maintained two lighthouse towers while living in a house between them. During a fierce storm, Abbie ran from tower to tower to keep the lighthouse lamps lit with whale oil. The following excerpt is from a discussion of the text:

> Student 1: [Abbie] had to be back and forth and she had to go, she probably, since the little light you can see in the picture, the house is in between both of them. So there was nothing between them [the two towers] that she could walk across. So when she's in one, she had to go all the way downstairs and walk up all those stairs and do that one [points to tower], then go down the stairs and up again.
> Student 2: You could think of a better way. They could have two [towers] but only keep one on, so that they only go up the stairs once.
> Student 3: Take care of one, and if they have something bad happen to it, then they could switch to the other one.

The literacy specialist noted that Student 1 applied the comprehension strategy of *summarizing* by paraphrasing the main character's problem. The engineer coded the same comment as *problem definition* because the student identified problems with the current lighthouse design. Specifically, the student noted that the design was inefficient because it required Abbie to walk up and down long flights of stairs in order to light each tower. This summary formed the basis for the group's future suggestions to the character, which later included a single-tower design or a walkway between the two towers.

In all, as suggested by these examples, we found that *summarizing* (a comprehension strategy) and *defining the problem* (a stage of the engineering design process) were often co-occurring processes that were both achieved in the same series of comments. While the National Reading Panel (2000) has asserted that summarizing can help to solidify students' understandings of texts (cf. Armbruster, Anderson, & Ostertag, 1987), research in engineering (Atman et al. 2007; Wilson et al., 2014) has asserted that summarizing can help students clarify their understandings of the problem that needs to be solved. Thus, as in these examples, summarizing can be considered both as a reading comprehension strategy and as a form of problem definition.

Visualizing

The comprehension strategy of *visualizing* often co-occurred with *modeling*, as students constructed mental images regarding what a character's solution looked like or what it should have looked like. For instance, one fifth-grade student imagined that Halvorsen would drop parachutes "with eight one-foot strings [with] the basket a little bit heavy so it wouldn't fly up into the parachute." She verbally explained what she had envisioned to the class, while pointing to a labeled illustration she had drawn. The literacy specialist identified this statement as *visualizing* because the student constructed visual images of what a character should do based on the written narrative. The engineer identified this statement as *modeling* because the student also began to specify particular solution elements, such as how long the parachute's strings should be and how many strings it should have.

As a second example, in the unit on solar ovens, students were introduced to a scenario in which a family was camping and wanted to make S'mores, but could not use a campfire. One third-grader drew and labeled a solar oven that was "450 inches long" because "wouldn't a small box not be good because wouldn't it get overheated and too hot, because there's too much in it, cause it's smaller?" Although this solution element was unrealistic, the engineer coded this example as *modeling* because the student tried to begin to conceptualize specific dimensions of her proposed solution. The literacy specialist also coded the student's comment as *visualizing* because the student began to construct mental images in relation to the problem presented in the text. (Upon further reflection, to aid in visualization, we could have provided a visual reference regarding how long 450 inches was, so the student could have constructed a more accurate mental image of that length and so she could reconsider whether she would build a solar oven that large to make S'mores for one family.)

The comprehension strategy of *visualizing* can entail asking students to draw images of what they envision as they read texts (Leopold & Leutner, 2012). Similarly, visual images are central to the work of many engineers as they reason through solutions to their problems (Dym & Brown, 2012). In short, visualizing can aid both in comprehension work (Sadoski & Willson, 2006) and in engineering design work (Joakim & Lindegaard, 2013). Indeed, the literacy specialist and engineer found that the two processes frequently appeared in the same set of comments in the data set.

Making Connections

Oftentimes, comments that had been coded as *making connections* were also coded as *defining the problem* (see Table 4). As one example, the fifth-grade students read *Brooklyn Bridge* (Curlee, 2001), in which the author described the "bends," a sickness faced by the workers who hauled debris in pressurized caissons as they constructed a stone tower. While reading this section of the text, one student described her own experiences in airplanes: "Once you go onto the plane, your ears close in. When you go up, there's less air because it's thinner. When you come down, it pops because there's more air." The literacy specialist coded this sentence as the comprehension strategy of *making connections* because the student drew from her past experience and connected it to the experience of the characters in the text.

The engineer, by contrast, coded this statement as *defining the problem*. When defining the problem, engineers must not only consider the specifications that their final products must meet, but they must also consider possible difficulties surrounding the implementation of their ideas (Dym & Little, 2009). In the context of this lesson, students drew from their past experiences as they sought to understand the problems associated with the construction of the Brooklyn Bridge. The students hypothesized that if relatively gradual changes in air pressure caused discomfort for them on pressurized planes, then sudden, major changes in air pressure could cause people to "become really sick." In this way, the students drew from their previous experiences to identify possible problems associated with laying foundations in pressurized caissons.

A second example will also illustrate how students drew from their background experiences to better understand the problem. As the third-graders read *Lighthouse Cat* (Stainton, 2004), one student stated, "You know when you have birthday cakes and you have candles on your birthday cake. You blow them out. It's just like wind, except it's not on a birthday cake. It comes and blows through and blows it out." According to the engineer, this quotation was an example of *problem definition* because the student identified a problem with the existing lighthouse design: It enabled the wind to "blow through" the structure and to extinguish the torches in the lighthouse, much as breath extinguishes a birthday candle. The literacy specialist coded this statement as *making connections* because the student used his experience with breath and candles as a metaphor to help him understand the behavior of wind and torches, the latter of which was described in the text. In all, the literacy specialist categorized a set of comments as *making connections*, a comprehension strategy, whereas the engineer coded those same comments as *problem definition.* As in these two examples, we found that students often made connections to background experiences as a means for understanding and articulating the problem.

Implications

This study expands previous research in science education (Pearson et al., 2010) and in mathematics education (Draper & Siebert, 2004), which identified common ground between disciplinary activity—such as scientific inquiry and mathematical problem solving—and reading comprehension strategies. This study illustrates how engineering design and reading comprehension strategies may share points of overlap as well. On a practical level, this study has implications for the many elementary teachers who want to integrate more science and engineering concepts into their curriculum but feel pressed for time (Blank, 2013). Although our instruction in the literacy block focused heavily on teacher modeling and student practice with *comprehension strategies*, we found that students who applied these comprehension strategies were usually also engaging in *engineering design processes*. Thus, we argue that literacy instruction and engineering instruction can often be accomplished in the same block of time, including in teachers' literacy blocks.

Many scholars (e.g., Conley, 2008; Gillis, 2014; Moje, 2008) have criticized the content area literacy approach to reading instruction, which emphasizes modeling and practicing generic comprehension strategies such as predicting and inferring, because this type of instruction detracts from authentic disciplinary activity. In contrast to this assertion, we found that a content area literacy approach did not preclude authentic disciplinary activity such as engaging in engineering design processes. In fact, we found that students' application of comprehension strategies (as determined by the literacy specialist) simultaneously co-occurred with their application of engineering design processes (as determined by the engineer). This study thus suggests that content area literacy instruction and disciplinary literacy instruction are not necessarily mutually exclusive because students' practice with generic comprehension strategies usually simultaneously co-occurred in conjunction with their practice of engineering design processes.

To be clear, we are not implying that all CSI leads to engineering design thinking. We purposefully selected texts whose characters faced problems that could be solved through the creation of a physical device or system. Consequently, as students actively sought to understand the text and possible courses of action for the character, they also actively sought to understand the character's problem and possible solutions. Thus, one possible component of engineering-infused literacy blocks may include careful text selection, including high-quality literature in which characters face problems that can be solved through engineering. Because the *Common Core State Standards* do not specify which texts should be taught, teachers have latitude in selecting texts that can foster engineering design thinking. Several of the texts that we chose were endorsed by the National Council for Social Studies (NCSS, 2015), the National Science Teachers Association (NSTA, 2015), and/or the National Council of Teachers of English (NCTE, 2015) on their lists of recommended books for children, ensuring that they were examples of high-quality children's literature.

Our study also suggests that some comprehension strategies co-occurred with certain stages of the engineering design process. Accordingly, we envision literacy instruction in which elementary teachers capitalize on points of overlap between particular engineering design processes and particular comprehension strategies. Figure 1 includes a model for elementary teachers that highlights how particular comprehension strategies co-occurred with particular engineering design processes. For instance, during the problem definition stage of the engineering design process, teachers and students could read the portion of the text that introduces a character's problem, and then stop and *summarize* the problem, *make connections* to similar problems they have had in the past, and *ask questions* to clarify what is confusing to them and to identify what they still need to know in order to help the character develop the solution. During the generating ideas stage of the engineering design process, students can *make predictions* about how the character will or should solve the problem, drawing from textual evidence to support their predictions.

During the evaluate ideas stage of the engineering design process, students can *make inferences* in regards to whether their suggested solutions were feasible or not, based on the evidence stated in the text as well as their background knowledge about the situation. Finally, during the modeling stage of the engineering design process, students can *visualize* what a character's solution is or should be, and draw and label images of their visualizations. We envision that this type of instruction would follow the gradual release model recommended by literacy professionals (Pearson & Gallagher, 1983), in which teachers explicitly model cognitive processes for students, and then provide students with opportunities to practice verbalizing the same cognitive processes.

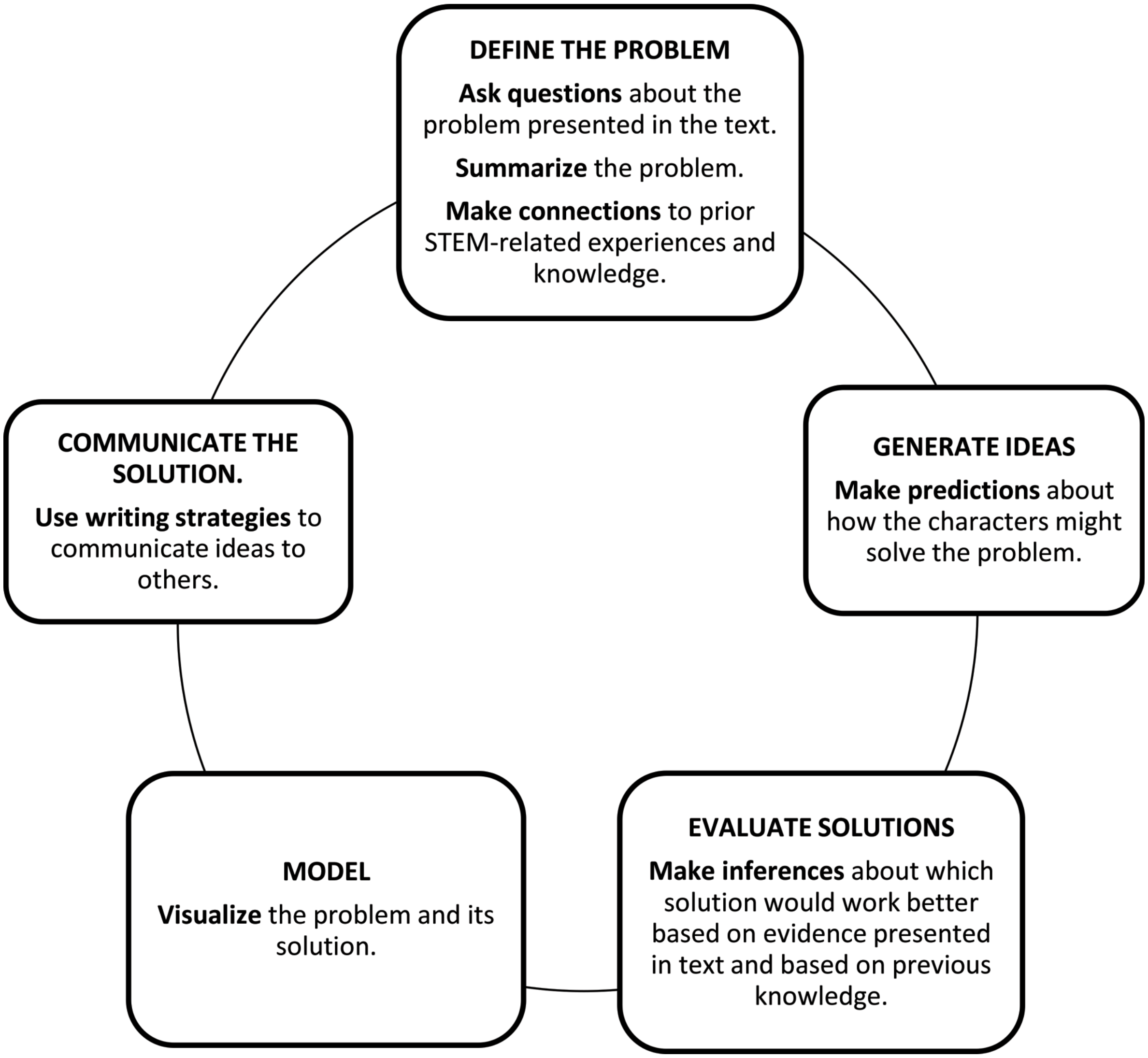

Figure 1. Model connecting engineering design processes to reading comprehension strategies.

Although we did not find overlaps between *communicating solutions* and comprehension strategies, we suspect that this finding is because of how we structured our classroom instruction. We did not ask students to communicate their final solutions until after they had tested physical prototypes of their designs, which occurred a week after they had read the narratives. Thus, because we did not ask students to communicate their solutions in the context of reading, we could not identify how this final stage of the engineering design process might relate to comprehension strategies. However, because *communicating solutions* entails writing, we imagine that teachers could effectively incorporate this aspect of the engineering design process into the writing portions of their literacy blocks.

In addition to offering implications for classroom practice, this study also offers implications for future research. This study resulted in a preliminary model (Figure 1) that illustrates how engineering design processes and reading comprehension strategies co-occurred in particular ways. Future confirmatory studies can determine whether more culturally, linguistically, and geographically diverse groups of students co-apply comprehension strategies and engineering design processes in similar or different ways, thereby leading to a more robust model connecting reading comprehension strategies and engineering design processes. This exploratory study suggests that reading comprehension strategies may be a promising approach for supporting engineering design work, but future confirmatory research can verify whether engineering-infused literacy instruction leads to gains in students' reading comprehension or in their application of engineering design processes.

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