Teacher Noticing and Pedagogical Content Knowledge in Engineering Design: Case Studies of Two Elementary Teachers

Introduction

The goal of the research presented here is to examine the resources teachers inexperienced in engineering bring to engineering design challenges in elementary classrooms. Engineering concepts, and specifically engineering design, have been incrementally added to K-12 standards and curricula in the last 20 years (Brophy, Klein, Portsmore, & Rogers, 2008; Katehi, Pearson, & Feder, 2009a; *Next Generation Science Standards: For States, By States*, 2013). In-service teachers who have never had coursework in engineering, or teaching engineering, will be tasked with finding or creating, and implementing, engineering design lessons; they will also be tasked with ensuring these lessons integrate learning objectives from existing disciplines and introducing new technology into their teaching repertoire (Crismond & Adams, 2012).

A large portion of the research on elementary engineering education focuses on evaluating professional development to prepare teachers for this new role (Duncan, Diefes-Dux, & Gentry, 2011; Poole, deGrazia, & Sullivan, 2001), or on the development of new curricula for teachers to employ in their classrooms (Cunningham & Hester, 2007; Foster, Husman, & Mendoza, 2013; Tank, Moore, & Pettis, 2013). Some studies have surveyed teachers’ beliefs and knowledge about teaching engineering (Hsu & Cardella, 2013; Hsu, Purzer, & Cardella, 2011; Kendall & Wendell, 2012; Loretto-Perdue, 2013), and attempted to construct frameworks of teachers' adoption and expertise (Sun & Strobel, 2013). However, fewer studies have focused on the finer-grained details of how teachers enact engineering lessons and interact with students in their classrooms (Hynes, 2012; Wendell, 2011). In this study, I constructed two cases of elementary teachers conducting engineering design challenges. Within those cases, I analyzed the way the teachers used their *pedagogical content knowledge*—through the frameworks of *teacher noticing* and *attention-dependent knowledge*—to relate to student thinking and make decisions in the classroom, and evaluate their practice through viewing video after the lesson enactment. *Teacher noticing* and *attention-dependent knowledge* were chosen for my analysis because engineering design, as a kind of open-ended problem solving, presents many opportunities for teachers to consider diverse student ideas and dynamically adapt their lessons to match student needs. I found that teachers did sometimes *interrogate* student thinking, but not always to the extent that they could accommodate this thinking in the lesson; additionally, teachers seemed to rely on their own understanding of engineering design when making pedagogical decisions. When reflecting on video of their practice, many of the teachers' choices during the lesson were elucidated; however, what they *noticed* from the videos regarding their pedagogical decisions and the thinking and actions of their students was not to such a level they recognized the connections between the two. Professional development addressing the teachers' engineering subject and pedagogical content knowledge, along with further video-club style analysis of their practice with groups of their colleagues, would likely improve teacher noticing during engineering design lessons.

Theoretical Background and Research Questions

Engineering Design and K-12 Education

At the beginning of the 21st century, support emerged from many national professional and educational entities for integrating engineering into K-12 education (International Technology Education Association, 2007; National Research Council, 2011; *Next Generation*

Science Standards: For States, By States, 2013). But what do these groups mean by "engineering?" The professional domain of engineering is two-fold, a knowledge base (*the engineering sciences*) and a process (*engineering design*) for solving human problems through the application of mathematics, science, and technology (Katehi et al., 2009a). Researchers (Hynes, 2012) have asserted that K-12 engineering education differs from professional engineering education in content and scope. The National Academy of Engineering (Katehi, Pearson, & Feder, 2009b) commissioned a report on the state of K-12 engineering education in the US, and the committee's first principle was that K-12 engineering education should emphasize engineering design, along with incorporating appropriate mathematical, scientific, and technological knowledge and skill, and engineering habits of mind. Therefore, *engineering design*, or the process by which engineers solve problems, is the facet of engineering represented in most K-12 engineering curricula and standards. Individual states, such as North Carolina, where this study took place, are in the process of adopting the Next Generation Science Standards, but also previously emphasized *Technology as Design* as a pathway, parallel to science as inquiry, by which students could acquire the science content contained in their standards (*Science Standard Course of Study and Grade Level Competencies*, 2004).

Professionally, Atman, Cardella, Turns, and Adams (2005) claim, "design is a central activity to all types of engineering" (p. 325), although the exact form of the *engineering design process* differs depending on which source and field of engineering you ask, and some would point out that any consensus model is too prescriptive for truly solving engineering design problems (Roozenburg & Cross, 1991). The process of design for students is generally assumed to be congruent to the design process of professionals, with experienced designers possessing a slightly more refined understanding of the process than beginning designers (Crismond &

Adams, 2012). Generally, however, the steps one engages in while solving engineering design problems can be distilled into three essential activities: *analysis*, including gathering information, problem framing, and re-designing; *synthesis*, through creating representations and modeling (often for planning), prototyping, or constructing a solution; and *evaluation,* most commonly through testing (Cross, 2000; Lawson, 2005; Smith & Tjandra, 1998). The cases in this paper examine students primarily involved in problem framing and planning, design activities for which research with elementary students exists; having prior analyses of student thinking during problem framing and planning allows us to later compare those findings with how the teachers' approach them in the classroom.

Problem framing in engineering education literature is described as "an engineer's process for scoping the peculiarities of a problem, gathering information, identifying criteria, constraints, and requirements" (McCormick & Watkins, 2015, p. 6), and it is an essential part of how engineers understand the nature of the design problem they are attempting to solve. Problem framing is an analytical activity, important not only at the beginning of the engineering design process, but also throughout subsequent revisions, where problem solvers determine the task at hand, identify given constraints and requirements, and potentially generate new ones as the refine their understanding of the design problem. Crismond and Adams (2012) describe problem framing as the activity of an *informed* designer, as opposed to *beginning* designers' problem solving, or treating the challenge as merely a well-defined problem and expecting the constraints and solution to be self-contained and self-evident. However, Roth (1995) describes 4^{th} and 5^{th}-grade elementary students exhibiting effective initial problem framing, and even reframing many aspects of the problem as they engaged in iterative revision of their solutions.

Several studies exists relating to elementary-aged students creating and using paper-and-pencil drawings for *planning*. Crismond and Adams (2012) predict beginning designers create representations which are superficial and do not approach the functionality of a design, but in their framework, beginning designer does not imply children. Rogers and Wallace (2000) discovered Kindergarteners' drawings for planning were not related to the making and assessing portions of their design process. Portsmore (2010) found that first-grade students' successful artifacts had a strong relationship between the drawing and the artifact, and suggests scaffolding planning for young students will encourage them to create more meaningful drawings. Johnsey (1995) suggests that drawing may represent the first prototype in a make-evaluate-make process in which elementary-aged students design. Clearly there is evidence that students do use drawings to inform their design process in some way, although not necessarily in a way which would be considered normative for experienced designers. Therefore teachers and curriculum developers should not design lessons expecting students to use drawings for planning as a professional engineer would.

We do not have holistic evidence for how elementary students progress through activities while engaged in engineering design, but researchers have established that experts do not progress step-by-step through any prescribed process while engaged in engineering design (Atman et al., 2007; Smith & Tjandra, 1998; Strobel & Pan, 2011). A simplistic model of the engineering design process is often presented to K-12 students in the same manner as the scientific method or the writing process (Connolly, Wendell, Wright, Jarvin, & Rogers, 2010; Cunningham & Hester, 2007), and is depicted as being a linear or circular series of steps (see Figure 1), with some variation between different curricula and state standards. The basic and seemingly prescriptive nature of these representations, which admittedly bear only a superficial resemblance to observed patterns of problem solving, has the potential to mislead novice teachers into rendering the engineering design process as a series of steps their students "have" to do, without imparting to the students the purpose and rationale for the steps (R. McCormick, 2004). When invoked appropriately, however, a standard model of the engineering design process can serve as a useful teaching tool (Hynes, 2009), and as such, the lesson planning materials provided to the teachers in this study included a sample engineering design process model similar to the ones in Figure 1 below.

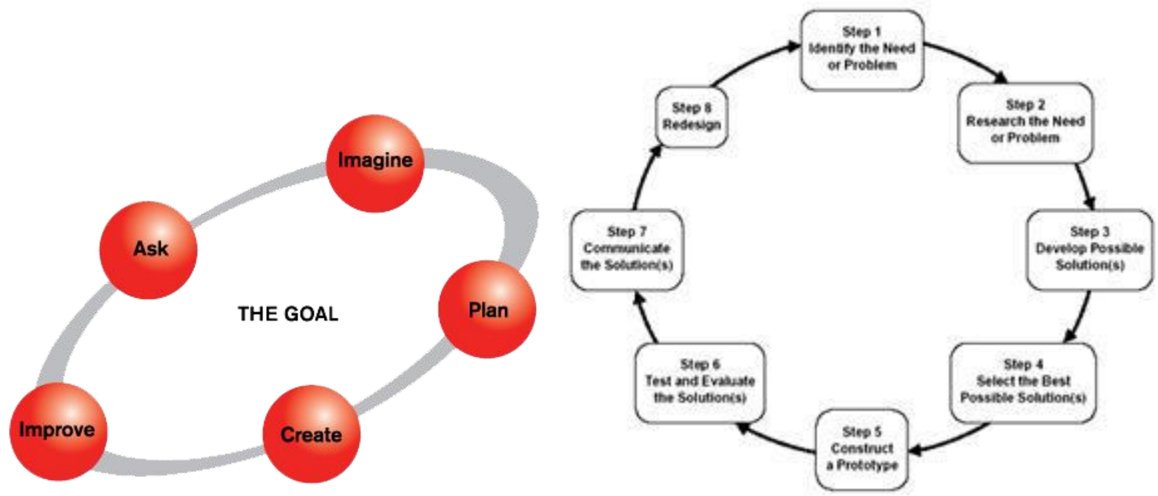

Figure 1: Common engineering design processes models from the state engineering standards in North Carolina (taken from Engineering is Elementary, Cunningham and Hester, 2007) where the study took place, and Massachusetts (Massachusetts Department of Education, 2006), where the lesson enacted during the study was developed.

Teachers Enacting Engineering Design Lessons

Because engineering design is a relatively new addition to state and national standards, and because few elementary teachers have outside engineering experience, teachers enacting engineering design lessons may be experts in other areas of teaching, but are generally novices in their knowledge with regard to engineering design (Crismond & Adams, 2012). Expert teachers have many forms of knowledge which aid them in their practice, such as *subject knowledge*, *general pedagogical knowledge*, and *pedagogical content knowledge* (Ball, 1990; Borko et al., 2000; Lampert, 1986, 1990; Shulman, 1986, 1987). *Subject knowledge* encompasses the actual domain knowledge the teacher should be responsible for understanding. *General pedagogical knowledge* would be practical and logistical information to assist in the practice of teaching regardless of the domain, such as how to construct a seating chart or deal with disruptive students. But within teaching specific domains, there is knowledge which goes beyond *subject* or *pedagogical* knowledge to optimize the teaching of that domain, and this is referred to as *pedagogical content knowledge*; this includes the most useful representations and analogies for relating content to students, demonstrations, anticipation of what material students will find easy or difficult, and the most common "misconceptions" of learners, to name a few (Shulman, 1986, 1987).

Regardless of engineering's novelty, educators with minimal experience in teaching engineering design have been shown to be effective in some settings. Hynes (2012) studied middle-school teachers who had recently completed professional development for engineering design, examining the teachers' engineering *pedagogical content knowledge* of the design process exhibited in the classroom during lesson enactments and through interviews. For many engineering design activities, specifically constructing a prototype and redesigning, the teachers' provided to their students’ "high" level explanations—including extensions beyond naming the activity, rational for the activity, and real-world examples of the activity—but many of the teachers still needed to develop their ideas of other activities in order to provide this level of explanation. Hynes' study, similar to this present study, relied on both pre- and post-interviews and classroom transcripts, and my study will build on his work by presenting a finer-grained analysis of teacher-student interaction regarding the engineering design process, targeted at the elementary-school level.

Wendell (2011), in a study of elementary teachers enacting engineering-design based science units, suggested that one challenge of teaching other disciplines through engineering design is that teachers need a strong understanding of the science *subject knowledge* applicable to the design problem in order to address students' difficulties in designing. She also demonstrated a connection between pedagogical actions, what she calls *patterns of interaction,* enacted by teachers, students, and the curriculum in the classroom, and improvements in student learning, and therefore claims these patterns may be markers of lessons where students were consistently oriented toward specific science concepts or engineering design principles. She concluded that elementary teachers with no academic training in engineering, and brief (in this case, three days) professional development, can be successful in implementing design-based curricula. Wendell's research uses video and transcripts from the lesson enactment to identify *patterns of interaction* and characterize the environment of each classroom, but the data she uses to determine student learning outcomes is derived from pre- and post-interviews of students, and thus provides only a generalization of the classroom environment compared to student performance outside of the context of the lesson. Additionally, although the teachers she studies are implementing engineering design challenges, it is in the service of teaching science; with the exception of design functionality, parsimony and explanation, focus is placed on gains in science knowledge, not design practice.

What this study hopes to add to Hynes' (2012) and Wendell's (2011) work is a more fine-grained exploration of the dynamic interactions between students' ideas about engineering design, and teachers' beliefs and actions, through an in-depth analysis of a select few episodes from the classroom, as well as teacher commentary on those episodes in the context of their objective for the engineering design lesson.

Engineering Design within Reformed STEM Pedagogy

If teachers are experienced with other STEM disciplines, such as science and mathematics, how might this relate to their *pedagogical content knowledge* for teaching engineering design? For at least two decades, mathematics and science education policy and research has supported reformed models of teaching that emphasize student-centered activities. In science, this has been achieved through inquiry-based environments: solving real-world problems, designing and conducting investigations, gathering and analyzing data, modeling, and reporting and explaining their findings (American Association for the Advancement of Science, 1993; Minstrell & Van Zee, 2000; National Research Council, 2000, 2011; Schneider, Krajcik, & Blumenfeld, 2005) In mathematics education, reform guidelines place their focus on thinking, reasoning, argumentation and problem solving, with an emphasis on connections and applications to the real world (Fennema, Franke, Carpenter, & Carey, 1993; Hiebert, 1997; National Council of Teachers of Mathematics, 1989, 2000). In many ways, engineering design activities, such as problem solving, explanation, modeling and testing (Crismond & Adams, 2012), have much in common with reformed theories of mathematics and science education. Because the teachers in this study operate in a school and district that follow standards and curricula informed by reform pedagogy, we can expect that they possess some *pedagogical content knowledge* that deals with student-centered instruction.

Why is it important that teachers place an importance on student thinking while enacting engineering design challenges? Reform pedagogy is closer to how professionals in STEM disciplines practice, and is a sharp contrast to the ways problem-solving is traditionally approached in schools. Textbook problems in science, mathematics, and engineering are generally *well-defined problems*, where there is usually one right solution emphasized (i.e., the solutions are *convergent*); all of the information needed to solve the problem—the variables, equations, methods—is given, either in the problem statement, within the book chapter, or previously during a lecture; and have a preferred, prescribed solution process (Jonassen, 1997; Jonassen, Strobel, & Lee, 2006; Schoenfeld, 1985). Problems that professionals (in engineering, science, or mathematics) encounter in their workplace are classified as *ill-structured problems*, that is, problems where one or more aspects of the problem are not well defined, or the information needed to solve them is not in the problem; that possess multiple solutions, solution paths, or no solutions at all (i.e., the solutions are *divergent*); have vaguely defined goals and unstated constraints; and require people to make judgments about the problem or solution, and defend them; among other things (Chi & Glaser, 1985; Jonassen, 1997; Jonassen et al., 2006).

If, as with other reform-based methods, we also want to introduce students to engineering design in a way that is *intellectually honest*, that is what Bruner (1960) and Ball (1993) would describe as representing a domain in a way that is true to its professional form but accessible to young learners, the design challenges they encounter should introduce them problems which are *ill-defined*, with *divergent* solutions. In order to handle this kind of problem solving in their classrooms, teachers will need the *pedagogical content knowledge* to implement more open-ended problem solving, including being able to recognize the diversity of thinking and solutions generated by posing *ill-defined* problems to students, whether in the form of engineering design challenges, inquiry-based science activities, or a classroom discussion on a mathematical concept, which necessitates paying careful attention to what students are thinking and saying (Ball, 1993; Cejka, 2005; Hammer, 1997; Jonassen, 1997).

Teacher Noticing

Within the literature on *pedagogical content knowledge*, *teacher noticing* is a concept which focuses explicitly on how the teacher discerns and responds to students' ideas; *teacher noticing* has generally been defined as attending to, and making sense of, events in an instructional setting (Sherin, Jacobs, & Philipp, 2011), including "(a) identifying what is important or noteworthy about a classroom situation; (b) making connections between the specifics of classroom interactions and the broader principles of teaching and learning they represent; and (c) using what one knows about the context to reason about classroom interactions" (van Es & Sherin, 2002, p. 573). To this end, Sherin and van Es (2005; 2011; 2008) have researched *teacher noticing* through the context of video clubs, where teachers and their colleagues view videos of these classroom encounters and are asked to analyze them. They claim that teachers utilize *teacher noticing* to adapt their instruction in the moment (van Es & Sherin, 2002), and that teachers need to learn to *notice*, so that they may "attend to aspects of classroom interactions that influence student learning and reason about them in the midst of instruction" (van Es, 2011, p. 134). They also point out that teachers may already have developed *noticing* skills in their classroom, but may not be utilizing what they observe, and act on it, in conjunction with their *content* and *pedagogical content knowledge,* in order to modify the lesson to suit the students' needs (van Es & Sherin, 2002). Exactly what student ideas and actions engineering design specifically calls for teachers to notice has not been addressed in the research literature, and will be examined through this study.

Several researchers in mathematics education have described other constructs related to *teacher noticing*, which may also prove to be useful tools for studying how teachers attend to, and respond to, their students' thoughts during engineering design challenges. Ball (1993) analyzes her attempts to teach third-grade mathematics in a way that is *intellectually honest*, addressing through case studies her top three dilemmas in doing so: distilling the content into representations that are relevant and palatable for her students; respecting her students' own mathematical thoughts, even when they do not conform to the established content standards; and creating a safe, productive learning community for her students. Ainley and Luntley (2007), working with teachers of primary and secondary school mathematics, presented a new theoretical construct, *attention-dependent knowledge*, which includes a "repertoire of attentional skills for attending to cognitive and affective aspects of pupil activity which may not be apparent to those without this experience" and contains knowledge which "cannot be written down….[but] becomes available during the complexity of the progress of a lesson, often in response to instances of pupil activity that could not be predicted on the basis of the teacher's subject or pedagogical knowledge" (2007, p. 4). In order to ascertain teachers' *attention-dependent knowledge*, their framework relies on both classroom observation data as well as later teacher reflections on their practice.

Teacher noticing has been put into practice within mathematics education, namely in the Cognitively Guided Instruction project (Carpenter, Fennema, & Franke, 1996; Franke & Kazemi, 2001), even though that project did not refer explicitly to teaching noticing as such. Researchers guided elementary-school teachers' interactions with students in a way that reveals their informal or intuitive knowledge of a subject, and then encouraged the teachers to organize their instruction to build on this prior knowledge. Carpenter, Fennema, and Franke (1996) claim that this approach helps teachers construct coherent, organized frameworks of their students' thinking and *pedagogical content knowledge*, thus building their own *general pedagogical knowledge* through solving problems within their classroom. Franke and Kazemi (2001) claim that teachers readily apply this cognitive framework to their interactions with students and other teachers, and that their intervention has lasting impacts on teachers' pedagogical methods for using student thinking to guide their instruction. Therefore, studying the ways in which teachers inexperienced with engineering design *notice* their students' ideas about design within engineering design lessons has potential benefit in subsequently encouraging those teachers to better understand their students thinking about the process of solving ill-defined problems and the divergent solutions they produce, and to use that thinking to help their students develop those solutions, rather than confining them to a pre-determined lesson plan.

Research Questions

The sum of the research on elementary teachers' *pedagogical content knowledge* of engineering is piecemeal. While theories of *teacher noticing* have been explored thoroughly in disciplines such as mathematics, no studies have examined how teachers use the student ideas they notice in the classroom to immediately inform the enactment of their lesson specifically with regard to teaching engineering design. Additionally, the studies that have looked at elementary engineering education have tended to focus on constructing broad frameworks, implementing curricula and guidelines for teacher professional development, rather than focusing on the individual practice of teachers enacting engineering design, and the ways they apply their *subject* and *pedagogical content knowledge*. Research in engineering education which has focused on teachers in the classroom have either targeted only their knowledge of engineering design without their *noticing* of student thinking about engineering design, or have generalized the classroom environment to explain student gains in post-interviews.

The goal of this study, as stated above, is to examine how teachers, as novices to teaching engineering, use their knowledge of engineering design and *noticing* of student thinking to inform their responses to student thinking during engineering design lessons. By analyzing pre- and post-interviews and teachers' practice in the classroom through the lens of the teachers' design *pedagogical content knowledge*, specifically the aspects of *teacher noticing* and *attention-dependent knowledge,* I hope to answer the following questions:

1) What do teachers *notice* about student thinking in the context of enacting engineering design lessons?
2) How do teachers interact with their students' ideas about engineering design during an engineering design lesson?

Methodology

Participants

This study took place in the Southeastern United States, at a magnet elementary school in the state's largest school district, with an enrollment of 800 students and around 50 classroom teachers. The school's demographics were representative of the state and district averages, with a 50% minority population and 30.9% free and reduced lunch population. The school had recently been named a STEM school by the district, which meant it was expected to integrate STEM across all subjects, and provide students increased opportunities for engaging in STEM activities such as science fairs and university/industry partnerships. Even before this designation, the school employed an Technology and Design teacher who saw students periodically in a manner similar to music or gym classes, although grade-level teachers as a whole did not have any particular STEM training, nor were they required to cover standards related to engineering in their classrooms. The attitudes toward engineering amongst the faculty were mixed; some teachers had no experience enacting engineering design lessons or using LEGO™ robotics tools, while other teachers already engaged in engineering design challenges with their students through science units or through afterschool clubs and activities. In the year this study took place, the school was about to begin a partnership with the Center for Engineering Education and Outreach at Tufts University to introduce engineering design with LEGO™ robotics into classrooms through a professional development and support program.

Before the program officially started, a pilot study of several classrooms was conducted to observe the teachers' pre-intervention. The two teachers involved in this study represented grade-levels at both ends of the elementary spectrum, 1st and 5th grade. They were invited by their principal to participate based on their perceived willingness and interest to engage in education research, and because they were experienced teachers and well-established at the school. The teachers participated in a one-hour professional development session to introduce the Chair for Mr. Bear engineering design lesson before enacting it in their classroom. Further background information on the teachers is given at the beginning of each case study.

Data Collection

There were three sources of data for this study: pre- and post-interviews, and classroom observations while the teachers were enacting the lesson (see Figure 2). These interviews and classroom lessons were videotaped and transcribed. In the classroom, the camera followed the teacher, focusing on his or her interactions with the students.

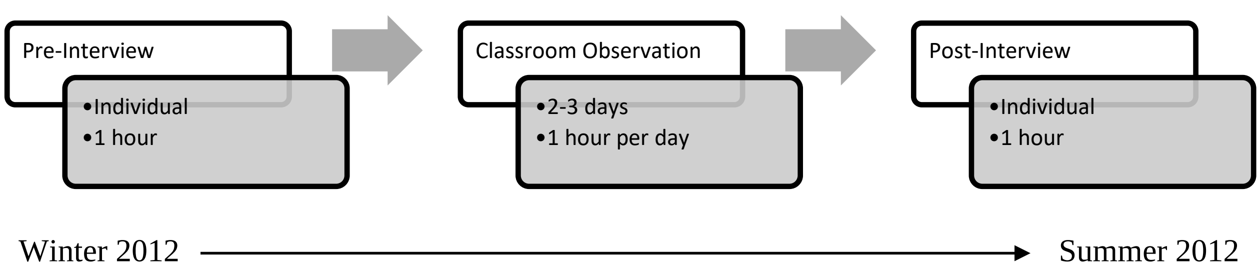

Figure 2: Overview of data collection events.

Interviews: Prior to any training or classroom exercises, the teachers participated in pre-interviews that explored their understandings and beliefs about engineering design, and its role in the elementary classroom (see Appendix for pre- and post-interview protocols). After the professional development and lesson enactment, teachers participated in post-interviews that centered around videos containing about 45 minutes worth of clips from their lesson implementation. The teachers were provided with the video clips ahead of the interview, and the clips were re-watched during the interview; the purpose of the post-interview was to elicit teacher reflection upon their practice during that lesson, specifically how their students met each teacher's objectives for the lesson, and their resultant thoughts about teaching engineering design. The structure of the post-interviews were inspired by Sherin and van Es' studies of teachers analyzing classroom practice through video clubs (Sherin & Van Es, 2005; van Es & Sherin, 2008). I describe how episodes were chosen using these interviews in the Data Selection section below.

Classroom Observation: The lesson enacted by the teacher participants in this study consisted of two parts: an introduction to engineering and an engineering design challenge. The first-grade class took two days to implement the entire lesson, and the fifth-grade class took three days. This present study analyzes only the engineering design challenge portion of the lesson, where students were presented with the task to “Build a Chair for Mr. Bear”(Connolly, Jarvin, Rogers, Wendell, & Wright, 2008). In their design, children had to meet six requirements in Table 1 below:

1)	Withstand being dropped from the student's ankle (the "drop test")
2)	Be the correct size for Mr. Bear (a roughly 6-inch-tall stuffed animal)
3)	Have a sturdy back
4)	Keep Mr. Bear from falling out
5)	Raise Mr. Bear at least one inch off the ground
6)	Use two different ways of connecting LEGO™ pieces together

Table 1. The six criteria for building a chair from the model lesson Build a Chair for Mr. Bear (Connolly et al., 2008) presented to the teachers as a template for their classroom activities.

This design task was chosen from a repository at the LEGO™ Engineering website (www.legoengineering.com) because it works with many different types of LEGO™ building sets, and has been implemented at various elementary grade-levels. The lesson materials were given to the teachers without differentiating for the range of student ages; this provided an opportunity for the teachers to modify the lesson to fit their students' needs, both before and during enactment. Both of the teachers I observed had added or modified content within the lesson during planning and enactment. During the engineering design challenge portion of the lesson, students worked in pairs through activities of the engineering design process such as planning, building, testing, and as time allowed, revising the solution. At the end of the design challenge, the lesson reviewed a sample engineering design process, similar to those found in Figure 1. Teachers were given discretion as to when the lesson would be enacted, how they would use the provided worksheets and rubrics, and whether the activities would be spread out over one lesson or several days.

Data Selection

The method for data selection broke the classroom instruction into "episodes" (Ainley & Luntley, 2007) of interaction between students and the teacher. In this study, the longer clips shown during the post-interviews were chosen because they featured the teachers frequently interacting with students, either through classroom discussions or one-on-one conversations with groups. One main theme of the post-interview protocol was asking the teachers to identify examples of students meeting or not meeting their objective for the lesson, from which shorter episodes were selected for analysis because they were referenced by the teachers in response to that prompt. The data below takes the form of two case studies, one for each teacher, each consisting of teacher background derived from the pre-interview; two episodes from a part of the lesson where students are working with partners to complete the engineering design challenge; and excerpts and analysis of the post-interview transcripts regarding the two episodes.

Data Analysis

Both the teachers' interaction with their students and their subsequent commentary were analyzed through the lens of two frameworks for *pedagogical content knowledge*. The framework derived from Sherin and van Es' research (2005; 2008) was used in this study's analysis of those post-interviews. The framework focuses specifically on the aspect of *teacher noticing*, “what is noticed and how teachers reason about what they observe” (van Es, 2011, p. 136).

<table>
<tr><th></th><th>Level 1 Baseline</th><th>Level 2 Mixed</th><th>Level 3 Focused</th><th>Level 4 Extended</th></tr>
<tr><td rowspan="2">What Teachers Notice</td><td rowspan="2">Attend to whole class environment, behavior, and learning and to teacher pedagogy</td><td>Primarily attend to teacher pedagogy</td><td rowspan="2">Attend to particular students’ mathematical thinking</td><td rowspan="2">Attend to the relationship between particular students’ mathematical thinking and between teaching strategies and student mathematical thinking</td></tr>
<tr><td>Begin to attend to particular students’ mathematical thinking and behaviors</td></tr>
<tr><td rowspan="7">How Teachers Notice</td><td>Form general impressions of what occurred</td><td>Form general impressions and highlight noteworthy events</td><td>Highlight noteworthy events</td><td>Highlight noteworthy events</td></tr>
<tr><td>Provide descriptive and evaluative comments</td><td>Provide primarily evaluative with some interpretive comments</td><td>Provide interpretive comments</td><td>Provide interpretive comments</td></tr>
<tr><td rowspan="5">Provide little or no evidence to support analysis</td><td rowspan="5">Begin to refer to specific events and interactions as evidence</td><td>Refer to specific events and interactions as evidence</td><td>Refer to specific events and interactions as evidence</td></tr>
<tr><td rowspan="4">Elaborate on events and interactions</td><td>Elaborate on events and interactions</td></tr>
<tr><td>Make connections between events and principles of teaching and learning</td></tr>
<tr><td>On the basis of interpretations, propose alternative pedagogical solutions</td></tr>
</table>

Table 2. Framework for learning to notice student mathematical thinking (van Es, 2011).

Van Es' framework for *teacher noticing*, however, does not include a category for whether teachers notice student ideas within the lesson as the lesson is being enacted, only in the commentary afterward. For this, Ainley and Luntley's (2007) construct of *attention-dependent knowledge* is very useful because it is situated in the classroom, and the episodes in this study were analyzed using two dimensions of their framework. The underlying focus of the episode was coded as either a *cognitive problem*, where the students exhibited an understanding of the engineering design problem that differed from the teachers' objectives, or a *cognitive opportunity*, where the teacher was trying to extend the students' thinking. This code was helpful in identifying how the teacher responds to an unanticipated idea or production from their students; for instance, whether they redirect the student back to the teacher's objective or allow the students' ideas to drive the lesson. The other code from Ainley and Luntley (2007), *noting/interrogating,* exemplifies the purpose the teacher has in their attention to their students' ideas. When teachers were *noting* their students' responses or actions, they did not attempt to elucidate their students' thinking, either because they were not interested in pursuing it, or they assumed they understood their students' reasoning already; when teachers were *interrogating* their student responses and actions, they were trying to gain a better understanding of their students' thinking.

Case Studies

Case 1: Problem Framing and Young Students

Fred had been teaching for thirty-eight years total when this study took place, largely in the early-elementary grades, but also sixth grade, and had certification in Special Education and a Masters degree in Literacy. He had spent twenty years teaching first grade, and in the pre-interview, seemed very comfortable with the classroom routines he described to me. He was one of the first teachers in the school to introduce LEGO™ building into the classroom, through the BuildtoExpress™ program, which asks students to answer open-ended, non-judgmental questions through building a scene or an object with LEGO™ bricks, figures, and accessories (LEGO Education North America, 2013). He had also enacted some LEGO™-designed lessons with the Simple Machines LEGO™ kits, where students followed building instructions to make contraptions with gears or lever mechanisms. Fred claimed he did not have any experience teaching engineering design, and admitted in the pre-interview that he did not know what the engineering design process was. However, he did describe several projects his students engaged in during science lessons, such as building a marble rollercoaster out of paper towel tubes, or engaging in free-play with LEGO™ kits when their classroom work was finished, in which his students were given open-ended opportunities to design and build. He tended to describe these activities as "play" or "science."

Episode 1: Students Problem Framing During Planning. The first episode in Fred's first-grade classroom took place while the students were engaged in planning and building activities during the Build a Chair for Mr. Bear engineering design challenge, and showcases how Fred negotiated his students' framing the problem presented in the challenge.

Fred made rounds of the classroom repeatedly throughout the planning time as students were using the worksheets provided with blank space for drawing and writing to individually plan their chairs, primarily checking in on the pairs of students and whether they were attending to the given design requirements (see Table 1). On a first pass around the room, he interacted with two pairs, Rosa and Emma, and Sam and Eric about how their design was meeting the requirements for the chair:

Fred:	What are you two girls talking about? What are you going to do for your chair?
Emma:	I'm going to have a wheel chair.
Fred:	Add wheels to it, ok. And what else do you need to make your chair sturdy?
Emma:	We're also going to make armrests like this.

Fred:	Oh, I like that. It will have armrests. Ok, what else?
Rosa:	A sturdy back.
Fred:	A sturdy back, ok.
Emma:	And it will have four legs.
Fred:	Four legs, I like that. Perfect. [Walks to next group.] Ok, listen, did you look at your chair and decide what you need on your chair?
Sam:	We have wheels.
Fred:	You think it’s going to have wheels. Ok.
Eric:	I think armrests. It needs to have a little cup holder on the armrests. I think it needs a place to put his feet.
Sam:	I think it needs to be a rocking chair.
Fred:	You want it to rock, ok. You can try and see what happens. Ok, what else?
Sam:	I think it needs to be comfortable.
Fred:	How is it going to be comfortable?
Eric:	It needs padding.
Fred:	We’re only going to have bricks to work with. Can you put padding on there with just the bricks?
Students:	No.
Eric:	We can pretend the bricks are padding.
Fred:	We just need to make sure it’s really sturdy, ok?

The first group, Rosa and Emma, had considered many of the requirements for the chair given in the lesson, such as arm-rests and a sturdy back (lines 5, 7) to keep the bear in the chair, and four legs (line 9) to raise it off the ground. They also included a new requirement, wheels (line 3), to which Fred replied "And what else do you need to make your chair sturdy?" (line 4) refocusing the girls to frame their problem with the requirements from the lesson. Although it was not a requirement given in the challenge, he did not dissuade them from planning to add wheels to their chair. The second group, Sam and Eric, included little in the description of their plan that would help them meet the requirements from the lesson. They described wheels (line 12), armrests with cup holders and a footrest (lines 14-15), and rockers (line 16), with Fred's replies remaining non-judgmental: "You think it's going to have wheels," or "You can try and see what happens" (lines 13, 17). When the boys introduced comfort as a new requirement for the chair, solved by adding padding (lines 18-20), Fred appeared to draw the line. "We’re only going to have bricks to work with. Can you put padding on there with just the bricks?" he asks (lines 21-22). When Eric suggested they could "pretend" the bricks are padding (line 24), Fred again refocused the students' framing of the problem to the original, and more tangible, requirements from the lesson, "We just need to make sure it's really sturdy, ok?" (line 25).

The way Fred considered student ideas about problem framing in this episode can sometimes be described as a *cognitive opportunity*, because Fred allowed the students to add their own requirements, such as wheels (line 3) or rockers (line 16), instead of insisting students only work on the six given requirements. Even if he did not actively encourage these extraneous requirements, he allowed his students to add them as their own personal goals for building. However, in the case of Sam and Eric's padding, his tone in the episode switched and he treated this problem scope as a *cognitive problem*; there is a difference between how he responded to students' plans to include wheels and rockers on the chair—non-judgmentally *noting* their ideas by echoing the students' responses (lines 6, 8, 13)—and how he responded to the students when they suggested adding padding to the chair—*interrogating* their plan by asking how they intended to build padding with only LEGO™ bricks (lines 20-25)—and immediately refocusing them to the overarching goal in building the chair, that it be sturdy. While other design elements might be negotiable, he implied to Sam and Eric that padding was not. It is also possible that the padding was the straw that broke the camel's back; Sam and Eric's growing list of requirements did not contribute to the sturdiness of the chair, and the suggestion to add wheels might have been similarly rebuked had it occurred last.

Episode 2: Students Problem Framing During Building. The *interrogating*/refocusing of Rosa and Emma's problem framing can also be seen to a lesser extent the first time Fred encountered them wanting to add wheels (line 4), but he let it go until later in the building stage of the lesson, in an episode which we will now examine. Fred revisited Rosa and Emma's group because they were having difficulty with their own plan to add four wheels to their chair:

Rosa:	I only have two wheels.
Fred:	Oh, my gosh, well, that's all you have to work with. Rosa, does it say your chair has to have wheels? Does it have to be able to move around? Does it say that on the paper?
Rosa:	[Shakes head yes.]
Fred:	Let's take a look and see, Rosa. Let's read this again. Build a sturdy chair for Mr. Bear that will withstand the drop test, we'll drop it on the floor, do you understand that? Be the correct size for Mr. Bear, so it has to be this long. Have a sturdy back; does your [desk] chair have a sturdy back? The chair you build has to have a sturdy back. It has to keep Mr. Bear from falling out. So that's what the armrests are for? It has to raise Mr. Bear at least one inch off the ground. So look at this chair, look how far off the ground it is. Your chair has to be that far off the ground [holding fingers an inch apart]. OK? Does it say anything about wheels?
Rosa:	No.
Fred:	Nope, so don't worry about wheels.

Rosa was having difficulty adding wheels to her four-legged chair because the LEGO™ kit they were using only included two wheels (line 26). Fred read through the six requirements from the lesson while inspecting her chair (lines 31-39), *interrogating* what she had built; although he gave her no opportunity to reply except with a yes or no, Fred was acknowledging that her attention was on a different aspect of the design of the chair than was his intention. Even more so than his suggestion to Sam and Eric just to focus on sturdiness (line 25), Fred treated Rosa's difficulty in adding wheels as a *cognitive problem*, explicitly establishing a problem frame for her from the challenge's original requirements by telling her unequivocally not to include wheels in her design (line 41). In the first episode, Fred only redirected Rosa and Emma toward sturdiness without dissuading them from reframing the problem by adding wheels. What caused Fred to change his attitude toward their additional requirement? Similarly, in the first episode Fred did not discourage Eric and Sam's plans to include wheels, cup holders, footrests, or rockers, but does challenge their desire to add padding. What might explain this inconsistency in the way Fred treated his students reframing the problem with these additional requirements? Answers to these questions were made clearer during the post-interview.

Post-interview: "As long as they built the chair, they're meeting the objective." In the post interview, we watched video clips including both episodes from Fred's class, discussing what met or did not meet Fred's objective during the lesson, which as he stated below was simply for students to build a chair:

Fred:	And there's one [group] where I wished I'd said something about, "Does your chair have wheels? Do you need to have wheels?" Because it's something that a lot of the kids, you know, all wanted wheels.
Interviewer:	It's an age thing.
Fred:	Yeah, and so, I think I would have made a point, because we had gone around the school and we took pictures of chairs all through the school, and some of them had wheels and some of them did not. And I think I probably would just pick chairs that didn't have wheels next time. Because the wheels are so big in the kit that it just makes it too hard to build it.
Interviewer:	I've known teachers to pull the wheels out of the kits, and in some cases you need them obviously, for Bear in a Chair you don't. So [Rosa and Emma] they're like, "I need two more wheels!" And you're like, "But you don't even need wheels at all!"
Fred:	Yup. They were kind of focused on they wanted their chair to move around.

Fred explained that he wished instead of allowing students to continue adding wheels to their chairs, that he had questioned their plans when wheels were initially brought up as a requirement (lines 42-44). He described Rosa and Emma from the second episode as "focused on [that] they wanted their chair to move around" (line 55), and attributed this inclusion in their problem framing to an activity they did before the design challenge where they walked around the school to view examples of chairs (lines 46-50). His proposed solution was to leave out examples of chairs with wheels when he repeated the activity next year.

We continued our conversation, discussing other requirements the students had added to the challenge, and Fred's overall objective for the lesson:

Interviewer:	I remember kids talking about cushioning when they were planning? How

	do you interpret that in terms of the objective of the lesson? Would you say that that's the kids not meeting the objective? Or...
Fred:	As long as they built the chair, they're meeting the objective. Whether they get hung up on something like that, like, I guess my job next time around is to make sure that they don't get caught, stuck on something like that.
Interviewer:	Ok, so your objective was for them to get to the end and have successfully completed the task.
Fred:	To meet the objectives of building the chair.
Interviewer	Were you surprised that kids were wanting to add wheels or cushions or colors?
Fred:	I really wasn't surprised with the wheels because every time we build something they want to add wheels to it. The cushioning I was surprised just because the product they were working with was not soft, so that was kind of interesting? But I can see where the chairs that we looked at and the chair that we have at home are all cushy, nicely padded chairs. But it didn't seem to be an issue once they talked about how they would like to have a cushion, but it didn't hold them up. It didn't stop them from continuing to build their chair.

Here, Fred explained his real motivation behind his choices to encourage or dissuade the requirements that students included in their plans: his ultimate objective for the lesson was that the students simply complete the chair (lines 59, 64), and he was comfortable with the students' own problem framing unless he felt it was going to impede their ability to make the chair sturdy. He was not surprised that students wanted to add wheels, but he seemed not to understand why students would attempt to include comfort as a requirement when the materials they were working with were obviously not soft (lines 67-70). With the cushions, as with the wheels, Fred attributes some of the student-generated requirements as being borne out of the chairs students observed as exemplars in their pre-building activity or their own everyday experiences (lines 70-71). From Fred's perspective, even if he did not understand Sam and Eric's desire to add cushioning, he felt that he could allow them to explore it as long as it "didn't stop them from continuing to build their chair" (lines 71-74). His actions in class contradict this claim, because he did verbally refocus them to the original requirement of sturdiness after they argued in favor of including cushions (line 25).

When further discussing student-generated requirements for the chair, I asked Fred how his students would react to generating their own requirements for the chair:

Interviewer:	What do you think would be different if—or do you even think a first grader could be capable—but I've known teachers in lessons to let the kids make their own objectives for the chair. So maybe, you know, they would have decided that an objective would be color, and they would have some way to test what the chair looked like in the end. I mean, what do you think that would that do?
Fred:	If you allowed the kids to switch bricks [between groups]. You know, that would be fine to do that. The other thing that we do in the, the LEGO [Build to Express™]is, we tell the kids that if you say "this is a red brick," if you're holding up a green brick, if you say it's a red brick, it's a red brick. So, I was kind of hoping that maybe they'd be able to make that connection from the other kit to this, you know, that if they didn't have what they needed, they could say this is the back, even if it's just one little piece, this is the back of the chair, and make that connection. But there are a few kids in here who would make that connection. So, it's again, it's how much they've used the LEGO [Build to Express™], and then start building with this, too, would make a big difference.
Interviewer:	So do you think that's something that they can, with enough experience in the classroom, that they can learn by the end of the year, like, to sort of put aside the physical appearance and do that?
Fred:	I mean, she [pointing at Rosa on the video] wouldn’t be able to get past that. Because if she still wanted something, a red chair, it's got to be red, and she would just stop at that point. Unless you could talk her through it.
Interviewer:	So, How did she do with [Build to Express™]?
Fred:	Actually she did very well with [Build to Express™]. Because they're watching the other children and the other students showing you pieces and saying, you know, this is a car, and it's just a plain brick, you know, eventually she caught on to, oh, it's a car. But it took a long time. She didn't get it for the first couple months of school.

Fred suggested that some students might have trouble re-framing the problem when they run into trouble building, letting go of requirements that might impede completing the chair; speaking specifically about Rosa (lines 95-97), "she would just stop at that point. Unless you could talk her through it," which is what he attempted to do in the second episode (lines 27-39).

Analysis. Fred came to the post-interview with a list of notes from his initial viewing of the video; most of Fred's reflections on the lesson regarded his own pedagogy, noting when he felt he should have discouraged wheels in Rosa and Emma's plan (lines 42-44) or that he should not include chairs with cushioning or wheels as example chairs for next year's lesson (lines 48-50, 70-71). He referred to specific events within the episode as evidence, such as Rosa's struggle with the wheels, but does so in an evaluative way, ascribing judgment to his and his students' performance (lines 81-97). But he also generalized the thoughts and capabilities of his students (lines 55, 100-102) without direct evidence from the video. In her framework for *teacher noticing*, van Es (2011) would consider these indicators of *Level 2*, or *Mixed* characteristics of *what* and *how* he noticed. What is missing for effective *teacher noticing*, she would argue, is discourse regarding the episode which is "more interpretive in nature, in which the teachers' goal is to make sense of student thinking and use evidence from practice to reason through important teaching and learning issues" (2011, p. 135).

After considering the post-interview data, some questions about Fred's actions during the two episodes are resolved (What caused Fred to change his attitude toward Rosa and Emma's reframing of the problem to include wheels? What might explain this inconsistency in the way Fred treated Sam and Eric's framing of the problem, versus Rosa and Emma's?), but new questions also arose. Fred's objective for the lesson, that students complete the chair, was extremely simplistic when compared to the six original requirements in the lesson and the requirements generated by his students. However, students repeatedly introduced requirements in their plans that Fred did not anticipate, which led to inconsistent reactions to how his students were framing the problem (e.g., including wheels or cushions). Fred's broad objective could have been capitalized on to encourage groups of students to follow the diverse design solutions it spawned, but instead he (implicitly, and based on the post-interview, possibly subconsciously) shifted the direction of his framing of the problem to favor only sturdiness. Fred also discouraged some students from considering requirements in their problem frame he believed would keep them from completing the chair, even if he had allowed other students to include those requirements in their problem framing.

Because he did not *interrogate* their thinking at the time, Fred made assumptions about his students' motivations (Rosa cannot look past adding wheels; therefore, the desire for wheels and padding comes from the exemplar chairs) and closed off an opportunity for turning *cognitive problems* into *opportunities*. During class, Fred did not attempt to elicit from Sam and Eric *why* they wished to add padding to the chair, only asking them to consider *how* they would accomplish it when their only materials were hard LEGO™ bricks. He also did not explain to Sam and Eric in class why "pretending" the bricks are soft (line 24) is not an acceptable option. Something about the intangible requirement of "comfort" (line18) made Fred's approach switch from *cognitive opportunity* to *cognitive problem*, but he based his opinion on the infeasibility of cushioning again on his own assumptions, not the thoughts of his students. In connection to van Es' *teacher noticing* framework, Fred did not reflect on his role in setting the students up for difficulty due to the vagueness of his objective, and the inconsistency of his responses; additionally, Fred expressed theories in the post-interview as to how to how he might minimize the student-added requirements of padding or wheels, but they were not necessarily grounded in the students' reason for adding these requirements. In the framework, an ideal awareness of this would be a *Level 4*, or *Extended*, to "attend to the relationship between teaching strategies and student thinking." Fred's practice might benefit greatly if he learned to not only acknowledge his students' ideas, but how to use them to inform the direction of his lesson.

Case 2: Expecting Students to Follow a Rigid Process

When this study took place, Jennifer had been teaching fourth and fifth grade for thirteen years. She had her bachelor's degree in elementary education, and a Master's degree in education with a specialization in science. She identified herself as very confident in teaching science, as her fifth-graders had a state standardized exam in science at the end of the year, and as a result had science class every day, unlike in the earlier grades. In the past, she had had an arrangement where she taught science not only to her own students, but also another fifth-grade class. Jennifer described having a structure for planning her science lessons, striving toward a balance between lecture, small group discussion, and hands-on experimentation. She reported engaging in engineering design during some science lessons, such as when her students built wooden racecars to test on a track. When I asked her about what she thought engineering looks like in an elementary classroom, she emphasized engineering as a process, talking about "having a purpose...and then planning to match that purpose, and then building and creating." She recognized that engineering was a broad field, and discussed several branches of engineering, noting that her father was a mechanical engineer. She also described engineering as being essentially the same thing as science, because "they both follow the same kind of processes."

Episode 1: No building before planning. As Jennifer passed out the papers and LEGO WeDo™ kits, she verbally provided her students with general instructions for the planning worksheet, which had space for drawings and writing, gave them a ten-minute time limit, and emphasized that this time was to be used for planning, not building:

Jennifer:	You and your partner getting this sheet of paper, and it has all of the same requirements that are up here (on the board). And it has space for you to draw and space for you to write. And you're going to draw a picture. You might have labels on your picture, so you know what pieces are what. We're not going to color them, because that's time consuming. But you might have some labels, you might have some notes, and you also need to describe (reading the worksheet) "Write about how you will make it." So, this thing right here (reading a requirement from the worksheet) "Use two ways of

	connecting'" that needs to be thought about as you're planning this out. Very important. Because if you kind of get going and you make the whole thing, you haven't thought about the idea of using two different ways, then you're probably going to have to go back to almost the beginning. ... Let me ask you something: should we hear LEGO™ bricks?
Students:	No.
Jennifer:	Yes, we should hear them. If you are making a plan, you need to know what is available, so you're going to be looking through it. Can I ask you guys a question? Should you be building it?
Students:	No.
Jennifer:	That's what you need to be thinking about. That's not an option right now because we have to have our plan first.

Jennifer's intentions in letting the students plan with the LEGO™ materials may not have been clear to her students, however (line 117), and she missed an opportunity to *interrogate* their seeming confusion over their task.

During the planning time, Jennifer circulated amongst the groups, asking questions about her students' plans, and occasionally clarifying her expectations for planning to the whole class. Jennifer stated early on in the post-interview that her objective for the lesson was that her students understand the importance planning, and that they plan through drawing and writing before engaging in building, as she explained to the class, albeit at the end of the planning time (lines 171-172 below). Beginning designers may have difficulty creating useful representations of their design ideas, often emphasizing superficial aspects which do not contribute to developing a solution (Crismond & Adams, 2012) and evidence suggests that very young designers benefit from adequate scaffolding in creating meaningful drawings for planning (Portsmore, 2010).

At one point, Jennifer came upon a group consisting of an English Language Learner (ELL) student and his partner, whom she surmised had crossed the line into actually building the chair, rather than just planning with the pieces:

Jennifer:	[Taking apart the students' chair as other students look on.] Should we start

	building?
Jae-Sun:	Um, aww. [Expressing disappointment.]
Jennifer:	Ok. Here’s what we’re learning. Here’s what we’re doing. We know what we have [in the kit], you can test out how this is going to fit [trying two pieces together], test them out, and know what you’re going to draw. Not quite building yet, so we have a plan and we know our goals. So, ok? We’re planning [points to planning worksheet] and then building? Yes, ma’am?
Jae-Sun:	Yes.
Jennifer:	I'll give them [the pieces] back to you now. [Pointing to Jae-Sun’s partner, who is writing on the planning sheet] Help him.

Jennifer *interrogated* Jae-Sun’s actions during planning—regarding them as a *cognitive problem* that clearly did not meet her objective of planning before building (line 130)—but she never *interrogated* him as to what he was attempting to build, or why, or whether he might be planning while building. Instead she physically took his construction apart in front of him (line 124). He literally said nothing in the exchange except echoing "yes" when she asked him to confirm that he understands her expectations for the planning period (lines 127-132). Ainley and Luntley (2007) do not include in their analysis teachers interpreting students' actions as representations of their ideas. Jennifer, however, may have relied on actions, and not on verbal interaction, because Jae-Sun has a limited grasp of English; whether she was justified or not, she seemed confident in her interpretation of his intent through his actions.

Shortly after this episode, she caught another group with a partially-built chair, and reacted the same way as she had with Jae-Sun, by taking their chair apart and chided them for building during the planning period:

David:	[To Jennifer, pointing at Kyle] They're building.
Jennifer:	They shouldn't be. [Begins to take Kyle's chair apart.]
David:	Laura is building.
Jennifer:	[Looks over to Laura's table] They're not building. [To David] I would like to know, you can probably answer that, right? Why was he [Kyle] building?
Kyle:	I thought we were supposed to be.
Jennifer:	[Shakes head no while continuing to take chair apart.]
Kyle:	We finished our plan.
David:	[Answering Jennifer's question] Because he wasn't listening?

Jennifer:	Well, or he didn't ask. That's always a possibility; sometimes that happens right? [Finishes taking chair apart.]

The only *interrogating* in this exchange was when the teacher asked David if he thought he could explain why Kyle was already building (lines 137-138). When Kyle explained that they thought they could start building once they had finished their plan, Jennifer implied that they should have asked for permission from her first (lines 144-145).

Episode 2: Were you a good planner? Jennifer interacted with other groups, who are generally meeting her objectives for planning:

Jennifer:	Do you guys have a plan? You're writing less than you're drawing. Is it finished?
Akeem:	Yes.
Jennifer:	Ok, you need to label it. That's a tiny picture, you need to label it. I'm thinking more along the lines of labeling what pieces you're using, so that you have an idea of your plan. Because if I look at that, I'm going to have a ton of questions, alright? You don't want me to have that many questions when you make that plan. Like, what are the pieces you're going to use? [To the next group] Look at you guys.
Jack:	We're trying to make the chair sturdy. Because we don't want something that will break and fall down.
Jennifer:	Ok, and the fact that the word "sturdy" is up there [in the requirements]. So, you've got good labels. Um, this...oh, you've got it. Good. I was going to say, "What are these things?" [Reading off their planning sheet] "Arm rest. Plate." Ok, what are you using for the legs? Make sure if you're using things, what is the height requirement?
Jack:	One inch.
Jennifer:	One inch off the ground. What's that there? [Pointing to their drawing.]
Jack:	Oh, that's a foot rest right there.

After the 10-minute planning time was over, she asked all the students to reflect:

Jennifer:	Take a moment to reflect on what just happened. I gave you a time limit, I told you what you needed to do, and I had to come back around to a bunch of you to remind you of what needed to be there. So were you a good planner? In your head, I don't want to know, were you a good planner just now? Some of you, yes. You did all the pieces of it: the label, you were still messing with the bricks, but you were also meeting the goal of filling out the plan. So, I will give you more time, because now you obviously have a better understanding of how important that planning time is. I will give you two more minutes, for those of you who are still writing, and that's it. At

that point, we're going to start building.

If Jennifer treated the interactions with her students' ideas in this episode as *cognitive problems*, it was only to suggest minor changes, such as the inclusion of labels on Akeem's drawings (lines 149-153). If anything, she *interrogated* her students' ideas more thoroughly when they were following her instructions than not, such as when trying to interpret Jack's drawing (lines 158-163). She followed her rounds throughout the classroom with a general announcement to the class, asking them to consider whether they were a "good planner," by including elements like labels on their worksheets, or utilizing the LEGO™ bricks for planning without building (lines 169-171). She made the interesting statement, "now you obviously have a better understanding of how important that planning time is" (lines 171-172). But, whether her students labeled their drawings, as Jack had, or skipped planning on paper to build instead, as Jae-Sun had, when and how did she assess that the students now understood the importance of formal planning? Is it possible that planning was happening in ways that were not captured on the planning worksheet? How could Jennifer tell whether her students were planning or building, or the purpose of their building during the planning period, without asking them?

Post-interview: "There's a possibility thinking is going on." When I asked Jennifer to expound upon why she thought planning was important enough to be the objective of the lesson (lines 171-172 above), she emphasized that it was "part of the process, like, when you think about your purpose with designing anything." Jennifer also described planning as considering the purpose of what you are making, so that you "put thought into the front end of making sure it does what it's supposed to do, at least in theory, then you're less likely to have a lot of work on the back end." Studies summarized in Portsmore (2010) suggest that fifth-graders may or may not engage in spontaneous planning, and Roth (1995) proposes that for 4th and 5th-graders, drawings represent not plans, but the first draft of a solution. Other studies, addressed in Crismond and Adams (2012), suggest that elementary-aged students may engage in planning through manipulating the building materials, and also points out that experienced designers continue to plan throughout the process, not only at the beginning. Additionally, the students in this school are fairly experienced at building with various LEGO™ sets by fifth-grade, through technology "specials" classes. Combined with the fact that the requirements from this lesson do not pose as daunting of a task for fifth-graders, it is likely there were students in the class who could successfully complete the challenge of building a chair, not necessarily without forethought, but at least without formally representing their plans via drawing with pencil and paper.

Jennifer seemed to differentiate between groups that were planning and groups that were not based solely on whether they had filled out the planning worksheet. She never asked Jae-Sun or Kyle for explanations as to why or what they were building before she took their constructions apart (lines 124, 136). I asked Jennifer if she could tell what a student was thinking based on their written plan:

Interviewer:	So, do you think that the planning then, the picture that they draw or the labels that they make, is that indicative, you think, about what is going on internally in their mind? Like, if you saw two groups, and one group had a really nice plan that they were working from and it was coherent and labeled and everything, and another group just kind of had a sketch that they weren't really playing attention to, would you judge what was going on internally with them, building, based on that plan?
Jennifer:	Um, I think it depends on the kids. And that's hard to say. I think I would, in the sense that I would immediately judge the situation as this group has put thought into this, and so they've done a whole bunch of work on their plan, therefore they're just now putting some energy into mimicking that in real life. This group, over here, may have just jotted some stuff down, and moved on, and now they're doing lots of work to try to make it go together because they didn't really think it all the way through. They just, kind of, meh, sketched it out and figured, "Oh, we'll deal with it when we get to it."

But then, after describing a hypothetical student who craves order and wants to plan every detail, versus another who wants to jump right in but recognizes that it might mean more work in the end, she concluded that students, by the fifth grade, begin to learn how their own minds operate:

Jennifer:	Kids start to learn that about themselves, or if they are the opposite of that, then they understand, "It's more important for me to do it this way, to plan it, I'm more successful like that." I don't know that I would ever say—I think that there's a possibility that the thinking is going on in both situations.

She conceded the "possibility that the thinking is going on in both situations," (lines 192-193) but does this satisfy her objective of students "understanding the importance of a plan?" How would she reconcile the two types of planners with her objective?

Interviewer:	Right, so you get a kid, like one kids with a very detailed plan and a chair, and another kid with, like scribbles and a chair, like, how do you tell that they've met the objective?
Jennifer:	Um, I would say that if my objective, if my objective is for them to see the importance of the plan? Then the kid without a plan didn't meet my objective.

Jennifer's metric for whether or not a student understands the *importance* of planning seemed to be tied to whether or not they followed her instructions for drawing and labeling their chair before building, rather than whether their plan was useful when the student constructed their chair or whether the students succeeded in building a chair, contradicting her statement above (lines 192-193) that planning could occur without formal drawing and writing.

We talked about whether her fifth-grade students had any difficulties completing the challenge, and Jennifer's biggest complaint was that students seemed to make a conscious choice, "I'm going to skip the planning," attributing it to laziness or impatience:

Interviewer:	Did you think that your students had any difficulties with the design challenge? I know we talked about some of the kids having trouble with planning, but just in general that kept them from successfully completing the challenge?
Jennifer:	I think that the planning part, it didn't even necessarily cause any problems with it, they just wanted to skip it. But I think as far as the idea of testing,

	you know they all understand and understood the reason behind, "Ok, I've got it, now I've got to test."
Interviewer:	But I could see in the video some of the kids were doing that, even before they picked up the rubric.
Jennifer:	And before they gave it to someone else, which I think was wonderful. Like, I just, that's something that I'm just like, good job! Because even if, in the midst of creating you're doing things to make sure it's ok. It's not as if you're not messing around with is as you're making it, to make sure of, "Ok, I put that piece on here for this reason, is it ok?" You're kind of testing as you go.

Jennifer scolded her students for building during the planning period, and yet she praised them for testing during the building period. She described students testing on their own before they traded their chairs for judging by other groups (lines 210-211), and also implied it would be hard not to test as you go along building (lines 212-215); similarly, it may have been hard for some of her students to plan with the bricks without building. Research on elementary students planning and making suggests that when students begin building before the complete their design planning, they gain experience in bridging between the actual and the possible (Roth, 2001), and that some students' way of thinking favors tinkering over top-down planning (Turkle & Papert, 1991).

Analysis. With regards to the questions posed after analyzing the episodes above (How did Jennifer assess that her students understood the importance of planning? How could she tell what her students were doing, or why, without explicitly asking them?) Jennifer exhibited *Level 1*, or *Baseline* noticing during this lesson enactment, in that she generalized student behavior and motivation, and sought little support from student thinking to support her primarily descriptive and evaluative comments during the post-interview. During this interview, Jennifer's commentary sometimes went beyond the whole class, beginning to notice individual students and also acknowledged patterns in hypothetical students who may have different ways of planning. But for the students in her class who did not meet her planning objective, she generalized their reluctance to plan as a conscious choice (line 205) rather than, say, a misunderstanding by an ELL student, or the result of a challenge that was simple enough to complete successfully without a plan. After the exercise, she announced in class that her students "obviously" understand the importance of planning (line 171), meeting her objective for the lesson, when in reality she was only monitoring whether a student had drawn a picture and labels (line 169-171), not whether the drawing actually constituted a plan, or whether they found their plan useful later in building, as she later claimed is the purpose of planning.

Several incongruities emerged between the way Jennifer structures her lessons, objectives and responds to student ideas, and the beliefs about the engineering design process she expressed in the post-interview. By segregating planning and building time in her initial planning instructions (lines 129-130), and not changing her expectations for the students after encountering several students who began to build while planning, Jennifer ignored her students' prior experience designing with LEGO™, as well as the opportunity to engage in hands-on planning with tangible materials, which might have benefitted some of her students. Jennifer acknowledged that (hypothetical) students may have different ways of planning, but denied that these are valid or useful ways of planning for this particular lesson, without validating that her requirements for planning were useful for students, or that the students' alternative ways of planning through tinkering are not valid. Similar to Fred, above, Jennifer did not recognize the relationship between her framing of the planning exercise and her students' thinking, which would exhibit *Level 4*, or *Extended* behavior. Her reluctance to allow students to build without drawing was only confounded by the availability of the LEGO™ sets during the planning period, which may have encouraged some students to begin building when they felt they had sufficiently planned their chair's design.

Jennifer also interpreted the engineering design process as a strict step-by-step formula and focused heavily on having her students follow the steps to the letter. Teachers with limited *pedagogical content knowledge* regarding the engineering design process are more likely to treat the process as rigid and pigeonhole activities into defined steps in the process (Hynes, 2012). McCormick (2004) describes a scenario very similar to this case, where teachers reduced problem-solving into a procedure the students "had" to do; "From their [students'] work, it looks as if students can carry out the process, but the recording process doesn't represent their thinking processes" (McCormick, 2004, p. 26). Not even expert designers follow the rigid engineering design processes modeled for elementary classrooms; we do not have a complete picture of how elementary-student novices design, but the information we have suggests that they do not engage in planning in typical ways useful to experts. Forcing students into a prescribed process may overshadow their natural design activities. Puzzlingly, while Jennifer disdained building during the time designated for planning, she did not have a problem with her students engaging in informal testing during the building period, and in fact praised them for it.

Discussion and Conclusion

This paper is part of a pilot-study for a research program that aims to bring engineering design to every classroom in an elementary school, through sustained professional development guiding teachers in creating their own lessons which incorporate engineering design challenges into their current required curricula. While some studies of *teacher noticing* have presented teachers' evolution throughout the course of year-long professional development(van Es, 2011; van Es & Sherin, 2008), this study presents two snap-shots of teachers, novices in teaching engineering, enacting a lesson containing an engineering design challenge, and then reflecting on that practice in post-interviews. My goal was to answer two questions, expounded upon below:

what do teachers notice regarding student thinking about engineering design in the classroom, and then, how do the teachers interact with those ideas?

1) What do teachers *notice* about student thinking in the context of enacting engineering design lessons?

In the post-interviews, both teachers reported their objective for their students during the engineering design lesson. While engineering design challenges presented to both classes were essentially the same, each teacher had their own area of the engineering design process they emphasized in their practice. The teachers profiled here clearly noticed their students' thoughts and participation in certain activities essential to engineering design: namely, problem framing (students' added requirements impeding their ability to complete the chair) and planning (students building before/without drawing a plan on paper). However, their expectations for these activities in the classroom, and their post-lesson commentary on their practice, shows that their understanding of these engineering design activities are somewhat naive. Also, using van Es' *teacher noticing framework* (2011), both teachers exhibited only level 1 and 2 behaviors in what and how they noticed during the engineering design lesson, despite having many years of general teaching experience, and did not notice the connections between their pedagogical choices in the classroom and their students' thinking. If these teachers exhibit higher-level *noticing* skills in other subject areas, which this study did not address, it would suggest that this expertise in connecting pedagogy and student ideas to practice either does not transfer from one subject area to another, or is linked to having a sophisticated amount of *pedagogical content knowledge* for that subject area. Having sufficient engineering *pedagogical content knowledge* may allow teachers to anticipate areas where students will have difficulties and feel more comfortable in adjusting lessons to suit the needs of the students. In this case, we would expect even veteran educators to develop *noticing* expertise when teaching engineering design only through instruction and experience specifically with engineering design.

2) How do teachers interact with their students' ideas about engineering design during the engineering design lesson?

While the teachers' objectives for the lesson were an important factor in their classroom behavior, the ways in which the teachers ensured their students met those objectives were not informed by knowledge of engineering subject matter or pedagogy, and often seemed contradictory to their stated beliefs in the post-interviews. Additionally, teachers did not always use what they noticed about student thinking to inform their pedagogical choices during the lesson. Fred was inconsistent in allowing his students to frame the chair problem because his paramount goal was to ensure his students simply completed their chairs; Jennifer touted the importance of planning but did not assess whether the plans were as important to her students as she assumed they were, and she did not allow for variations in students' preferred mode of planning, chiding students who built during the planning period, but praising students who tested during the building period. Both teachers exhibited a lack of thoroughly *interrogating* their students' ideas, instead making assumptions about their students' motivation, and were not shown to modify the lesson to accommodate their students' differing ideas. However, the post-interview analysis, and what the teachers *noticed* about their practice in the video clips, shed light on their motivation. Teachers frequently cited their previous experience or conceptions of student thinking in explaining student behavior, rather than actually investigating the thinking of students in the classroom. A simple question of, "Why do you want to include wheels," or "Why are you building instead of drawing?" would have shed light on student ideas, and possibly encouraged the teacher to modify their practice to accommodate them.

Implications and Future Work. This research has demonstrated that teachers pursue their lesson objective with little regard to feedback from student thinking, and often in contradiction to their expressed beliefs during post-interviews. In order to help teachers allow student thinking to inform their instruction, professional development should focus on developing *noticing* and *attention-dependent knowledge* specifically in the context of engineering design, along with *pedagogical content knowledge*, to ensure teachers have well-developed ideas of the engineering design process, and that they have elementary-appropriate expectations for their students' activities within engineering design. To facilitate this, it will be necessary to collect more data on how elementary students think about, and solve, engineering design problems, and also consider novice teachers' conceptions about engineering design along with their *pedagogical content knowledge*; Crismond and Adams' (2012) *Informed Design Teaching and Learning Matrix* provides a promising framework from which to base that research.

While video clubs and *teacher noticing* frameworks, à la van Es and Sherin (2008), were helpful for considering the ways the teachers thought about practice outside of the classroom, the aspects of *attention-dependent knowledge* (Ainley & Luntley, 2007) which specifically pertained to the decisions and actions of the teacher inside of the classroom were unique to that framework, and essential for analyzing how *teacher noticing* was applied during practice. Another avenue of study could examine the role of professional development, including video club discussions, in facilitating the development of *teacher noticing* and *pedagogical content knowledge* for engineering between novice teachers and those more experienced with teaching engineering. Video clubs may also provide a way to evaluate teachers' progress in these areas over the course of several lesson enactments and professional development sessions during the school year.

Sun and Strobel's (2013) *Stages of EEE Expertise Development* was published too late to be used in this paper's analysis, but shows potential for addressing the best practices of elementary engineering teachers with regard to *pedagogical content knowledge.* The two frameworks Sun and Strobel present center around both the effect of elementary teachers as they adopt engineering curricula, and skill with which they contextualize and make authentic the curricula they design and enact. While some of the stages in the frameworks are tangentially related to the issues of *teacher noticing* raised in this paper (e.g., A teacher who is more confident or comfortable with engineering curriculum may be more likely to deviate from the lesson to accommodate avenues responding to student thinking), direct references to students' "learning needs" are found in the framework strand on contextualizing lessons in "real-life" problem solving, which does not necessarily address noticing and responding to student ideas dynamically during the lesson.

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Appendix

Pre-interview protocol

1) BACKGROUND
   a) Name
   b) What grade?
   c) How many students?
   d) What grades have you taught?
   e) How long have you been teaching?
   f) Degree(s)?
   g) Certification?
   h) What subjects do you teach in your classroom?
   i) How much time do you generally spend teaching science? (hours and days per week)

2) SCIENCE
   a) What, in your view, is science?
   b) What makes science different from other disciplines
      i) of inquiry, e.g., religion, philosophy?
      ii) of STEM, e.g., **math**, **engineering**?
   c) What is an experiment?
      i) Does the development of scientific knowledge require experiments? (example)
   d) After scientists have developed a scientific theory, does the theory ever change? (example)
   e) Do scientists use their creativity and imagination during their experiments/investigations when trying to find answers to questions they put forth?
   f) Do you think science is universal, or does it reflect social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced?
   g) It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

3) ENGINEERING
   a) What, in your view, is engineering?
      i) What does an engineer do?
   b) *What makes engineering from other disciplines?*
   c) What is engineering design?
      i) Can you give an example of something designed or engineered?
   d) After engineers have designed an object, is there ever a need to change or re-design the object? (example)
   e) Do engineers use their creativity and imagination during their designing when trying to solutions to the problems they are addressing?

4) IN THE CLASSROOM:
   a) Comfort level teaching
      i) science, 1-5 with 1 = very comfortable and 5 = very uncomfortable
      ii) math
   b) What is your favorite science unit to teach and why?
   c) What is your least favorite science unit to teach and why?
   d) What does science look like in your classroom?
      i) facts/lecture
      ii) inquiry
      iii) assessment of understanding
   e) What does math look like in your classroom?
   f) In science, how do you assess student understanding about a topic? (pre and post instruction)

g) Do you use any tools in your classroom to teach science and math?
h) Do you ever use LEGO in your classroom? For what?
i) Do you have any special training or experience teaching STEM?

5) TEACHING ENGINEERING
a) What do you think engineering looks like in an elementary classroom?
b) What role do you seen engineering playing with respect to science, math, standards?
c) How will doing engineering in your classroom affect students (good or bad)

Post-interview protocol

Before the interview:

- Ask teachers to identify their learning objective for the Chair for Mr. Bear lesson.
- Ask teachers to select a video clip (5-10 minutes) from their lesson of a student (or group of students) meeting the learning objective, and a clip (5-10 minutes) of a student (or group of students) struggling to meet the learning objective.

Questions regarding the video clips:

- What parts of the lesson worked well for you and your class? Why did you originally decide to include these elements (be they themes, vocabulary, classroom management schemes, activities, questions) in the lesson?
- What parts of the lesson didn't work well for you and your class? Why did you originally decide to include these elements? Looking back, what would you change about those aspects of the lesson?
- What was your learning objective for the Chair for Mr. Bear lesson?
- How did you assess whether the students were meeting the lesson objectives during the lesson and after the lesson had been completed? What role did the actual student artifact play in your assessment?
- Do you feel the students had any "misconceptions" (use appropriate teacher-defined word here) regarding the objectives or content of the Chair for Mr. Bear lesson?
- What do you think were the difficulties your students had with the design challenge, and did they keep them from completing the challenge successfully? Is it necessary to complete the challenge successfully in order for the students to meet the lesson objectives?

Questions regarding engineering in general:

- Based on your enactment of C4MB, what is your comfort level (1-5) teaching engineering?
- Did you use your knowledge of how to teach science, or any other subject, to help you plan and enact this lesson?
- How would you characterize the kinds of "activities" your students did during the C4MB lesson? [And how do they compare to science, and Build to Express?]
- What would you estimate the balance of teacher talking/student talking/student independent working was during the C4MB lesson? What do you feel the percentages should be? How could you modify this?
- What was the reading/writing/doing balance for the C4MB lesson? Would you want to adjust these numbers, and if yes, how?
- Could you envision tying engineering into other subjects you teach? How would you accomplish this, and how would it compare to the ways you integrate the other subjects into your science lessons?
- How important was the engineering design process in your lesson? Do you think the process is a valid construct for elementary-aged students? How did the engineering design process relate to your objective for the lessons?
- Do you think it's important that students have time to improve upon their design solutions? Why?

______________________________’s Engineer’s Journal

Partner: __________________________ **Date:** ___________

Introduction to Engineering

1. Draw a picture of yourself doing engineering. Write a sentence or two about your picture.

____

____

____

____

Which items are engineered?

Item 1	**Item 2**	**Item 3**	**Item 4**	**Item 5**

What is Engineering Design?

Engineering design is the process of creating solutions to human problems through creativity and the application of math, science, and technology.

Even the chairs at your desk were engineered. What qualities of your chair would an engineer have to think about while designing it?

Challenge: Build a sturdy chair for Mr. Bear that will

- withstand the drop test
- be the correct size for Mr. Bear
- have a sturdy back high enough for Mr. Bear
- keep Mr. Bear from falling out
- raise Mr. Bear at least one inch off the ground
- use two different ways of connecting LEGO pieces together

Draw a picture of the chair you plan to build using your LEGO pieces. Write about how you will make it.

Chair for Mr. Bear Rubric

	Circle your rating below.	**Explain how you can turn the "No" into a "Yes"**
Does the chair pass the drop test from the ankle?	Yes No	
Does the chair seat have enough room for Mr. Bear to sit?	Yes No	
Does the chair have a sturdy back that is high enough for Mr. Bear?	Yes No	
Does the chair keep Mr. Bear from falling out?	Yes No	
Does the chair raise Mr. Bear at least one inch off the ground?	Yes No	
Did you use at least two different ways of connecting the LEGO pieces together?	Yes No	