What is an Engineer? Implications of Elementary School Student Conceptions for Engineering Education

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BACKGROUND
Research in engineering education tends to focus on students’ factual knowledge about engineering, their interests and attitudes, and on students’ conceptions of the engineer and the relation to curriculum development. Thus, it is essential to expand our understanding of students’ conceptions about the engineer phenomenon as the foundation for informing STEM education standards and curriculum.

PURPOSE (HYPOTHESIS)
The purpose of this study was to investigate students’ conceptions about engineers specifically: (1) What are elementary school students’ conceptions of an engineer? (2) How might students’ conceptions vary by grade level, gender, and community setting? (3) What are implications of students’ conceptions for engineering education?

DESIGN/METHOD
This study was descriptive in nature and reflected a cross-age design involving the collection of qualitative data from about 400 Grade 1 through 5 students from urban and suburban schools located in the Midwest, United States. Data were analyzed using content analysis and statistical testing.

RESULTS
Students conceptualized an engineer as a mechanic, laborer, and technician. Students’ conceptions entailed the engineer fixing, building, or making and using vehicles, engines, and tools. Students’ conceptions were relatively consistent across urban and suburban school communities with the exceptions that laborer was more common among urban students and technician was more common among suburban students. More than half of the students who drew a person drew male engineers.

CONCLUSIONS
A framework for organizing and interpreting students’ conceptions is presented. Curricular recommendations and implications are made that build on students’ conceptions and reinforce connections between national standards and the engineer concept.

KEYWORDS
elementary, engineer, student conceptions
students’ conceptions of engineers and engineering lacks the breadth necessary to support large-scale insights and models (National Academy of Engineering [NAE], 2008). Related research in engineering education tends to focus on students’ factual knowledge about what engineering entails and/or what an engineer does and their attitudes toward engineering and less on students’ conceptions of engineering (NAE, 2008) and the use of multiple data sources to support students’ conceptions. Thus, it is essential for research in engineering education to continue to expand our understanding of students’ conceptions about engineering phenomenon and the work of engineers as the foundation for informing standards and curriculum in K-12 science, technology, engineering, and mathematics education.

For the purpose of this paper, we focus on children’s conceptions of engineers and use two key sources of data from a larger study to describe, analyze, and support evidence-based claims for what students’ conceptions are and how their conceptions may have implications for planning curriculum and designing instruction that builds on these conceptions (Driver, Squires, Rushworth, & Wood-Robinson, 1994). In other words, we explicate students’ conceptions of an engineer. This study is not an attempt to identify or articulate the origin or development of students’ conceptualizations, nor is this an attempt to report on a quasi-experimental study of students’ conceptualizations before and after engaging in engineering-related activities. Hence, we focus on what students’ ideas are, organize and analyze these ideas, then make curriculum recommendations that incorporate students’ conceptions and the National Research Council (National Research Council [NRC], 1996) Science Education Standards and the ISTE (2007) National Educational Technology Standards [NETS].

**RELATED LITERATURE ON CHILDREN’S CONCEPTIONS AND LEARNING OF ENGINEERING**

Previous studies indicate that elementary school students are unfamiliar with the work of engineers. Oware, Capobianco, and Diefes-Dux (2007) found that students associated engineering with fixing, building, and working on things, and when asked to draw engineers, students portrayed engineers as physical laborers. In some cases students believed that in order for engineers to perform their work, engineers needed materials or objects, such as blueprints, computers, and safety gear. Similarly, Cunningham, Lachapelle, and Lindgren-Streicher (2005) found that students generally associated fixing, building, and vehicles with engineering. As a result, it has been deemed necessary to design curriculum to address students’ misconceptions and to help them gain a more informed understanding of engineering.

Hester and Cunningham (2007) list several reasons why elementary school students should be introduced to engineering. First, because of their interest in building, children already “engineer informally.” Second, engineering can be used to integrate other subjects and helps improve problem-solving skills. Finally, the authors state that “learning about engineering will increase students’ awareness of and access to scientific and technical careers” (p. 2). Despite the many benefits of including engineering in the elementary school curriculum, this can be a difficult task, as there is not always space available in the curriculum for engineering, and teachers rarely feel comfortable teaching engineering (Barger, Gilbert, Poth, & Little, 2006; Hester & Cunningham, 2007).

Regardless, there have been several attempts at incorporating engineering into the elementary school setting. Barger, Gilbert, Poth, and Little (2006) provide an example. In
their school, engineering is not taught as a separate subject, but is instead used as the “primary tool to connect the different required subjects” they teach, which works because of the multidisciplinary nature of engineering (p. 3). This approach to elementary engineering has provided positive results for the school, in terms of improved reading and math scores and in terms of student behavior (Barger et al., 2006).

Engineering is Elementary [EiE] (2011) is another example of a way to incorporate engineering into the elementary classroom. Hester and Cunningham (2007) write that the goals of EiE are to “increase children’s technological literacy,” “increase elementary educators’ abilities to teach engineering and technology to their students,” and “modify systems of education to include engineering at the elementary level” (pp. 2-3). The activities are designed to include a science topic, an engineering discipline, and a design challenge, all set in the context of stories and characters from different countries. Throughout the activities, students learn about and use the engineering design process which consists of the following steps: ask, imagine, plan, create, and improve (Hester & Cunningham, 2007). The use of EiE in the classroom setting has resulted in students having more informed conceptions of engineers, engineering, and the engineering design process (Cunningham & Lachapelle, 2007; Hotaling, McGrath, McKay, Shields, Lowes, Cunningham, Lachapelle, & Yao, 2007).

**Significance of the Study**

Our working definition for engineering is grounded in the National Academy of Engineering’s Changing the Conversation (2008) positioning statement. We describe engineering as a profession in which engineers “constantly discover how to improve our lives by creating bold new solutions that connect science to life in unexpected, forward-thinking ways” (NAE, 2008, p. 5). Engineers integrate different types of skills and knowledge in an effort to solve ill-structured problems that meet people’s needs. An understanding of engineering is essential to comprehending issues about design, innovation, and/or technical advancement. This is salient given that the fields of engineering and technology are undergoing rapid change in terms of creating alternative fuel sources, designing better medicines, providing access to clean water, and securing cyberspace (NAE, 2008). According to the National Academy of Engineering (2008) most students (1) understand that engineers “design and build things” but have limited sense of what engineers actually do; (2) have a positive impression of engineers, but many feel that they are not “smart enough to become engineers”; (3) see engineering as “hard work”; and (4) believe engineering work is sedentary, computer-based, and done in isolation (pp. 6–7). This is compounded by parents’ ideas of engineering as a means of “job security” and/or “career advancement and success” (2008, p. 7). In short, the public has a poor idea of what engineers actually do on a day-to-day basis, and there is a recurring message that engineering is not “for everyone.” Missing from current messages are the essential characteristics of engineering, such as creativity, teamwork, an ethic of care, and communication (NAE, 2008; NAE & NRC, 2009). The continued lack of diversity in engineering, as compared to the U.S. population as a whole, is thought to be linked to the narrow vision of the work of engineers and the impact of engineering (NAE, 2008).

Although a variety of useful tactics have been tried (e.g., outreach activities in secondary schools), no consistent message has been communicated (NAE, 2008). Most outreach initiatives, for example, target high school students with the aim of preparing the engineering pipeline (NAE, 2008). Considerably less attention has been paid to elementary and middle
school students, where such important efforts would serve a “mainline” function of promoting technological literacy and stimulating long-term interest in mathematics and science. Therefore, if engineering education is to promote a technological and scientific citizenry that is knowledgeable about engineering and the work of engineers, it is essential to determine how students conceptualize engineering in order to plan curriculum, design instruction, and create new policies or benchmarks for state-wide science, mathematics, and technology education standards that build on and are inclusive of these conceptions.

RESEARCH QUESTIONS

This research study is guided by the following questions: (a) what are elementary school students’ conceptions of an engineer?, (b) how might students’ conceptions vary by grade level, gender, and community setting?, (c) what are implications of students’ conceptions for engineering education?

THEORETICAL AND METHODOLOGICAL FRAMEWORKS

This study is guided by a theoretical and methodological framework grounded in constructivism. First, we describe constructivism and its application to our research work. Second, we elaborate on a subset of literature related to constructivism, more specifically, Piagetian theory. We use these theories as a way of supporting our constructions of students’ use of language and symbols through drawings and interviews to represent their conceptions of an engineer. In short, we create constructions about students’ constructions and use these respective constructivist perspectives to explain and support our constructions.

Constructivism

Constructivism, from a theoretical perspective, aims to understand the meanings constructed by students participating in context-specific activities using language (Schwandt, 1994). Central to this study was the written and oral language (words) and symbols (drawings) used by students as part of an engineering drawing task and interview to represent and communicate their meaning (Ehrlen, 2009; Holstein & Bugriuim, 1994; Kress, Jewitt, Ogborn, & Tsatsarelis, 2001). These signs and symbols represent the students’ interests, motivation, and what they view as crucial and salient for their purpose in making the sign or symbol (Kress et al., 2001). Students generate the meaning for words, such as engineer, in part based on their prior experiences and existing conceptions (Schollum & Osborne, 1987).

Similarly, the researchers in this study constructed an understanding of the language and symbols the students used to represent their conceptions of an engineer—the researchers created constructions about the students’ constructions. Thus, meanings were constructed by the researchers within a sociocultural context. Therefore, the codes and categories constructed by the researchers were shaped and informed by our experiences and conceptions of an engineer. Our interpretations of the students’ responses, then, were simply interpretations grounded in our experiences, conceptions, and perspectives about engineers that were grounded in engineering, science, and technology education (Patton, 2002).

Cognitive Constructivism - Piaget and Representation

Cognitive constructivism is based on the work of developmental psychologist Jean Piaget. Piaget’s theoretical research work encompassed four different phases: (1) the sociological
model of development; (2) the biological model of intellectual development; (3) the elaboration of the logical model of intellectual development; and (4) the study of figurative thought (Beilin, 1992; Piaget, 1964). Most researchers know Piaget’s theory of development that describes how children develop cognitive abilities. For the purpose of this study, we focus on Piaget’s later work, more specifically, the figurative processes and how children represent their own mental images.

Piaget and his colleague Inhelder believed that by two years of age, children are able to represent the world to themselves (1971). Through their elementary school years, children are bound by their concrete perceptual experiences and are able to represent those experiences from their own perspectives (Eliot, 1987). In other words, children are able to assimilate concrete experiences, such as those introduced by classroom learning activities, and are also able to represent their own ideas of their experiences. Piaget and Inhelder (1971) described children’s representation as the semiotic function, which is the capacity to represent a signified entity with the help of a signifier (e.g., word, expression, or image). They distinguished between symbols (i.e., signifiers that have some link to what they represent) and signs (i.e., signifiers that are arbitrary and have a conventional relation to what they represent). Symbols can be creations of the individual child, whereas signs are conventional and collective (Piaget & Inhelder, 1971). Piaget and Inhelder believed that the degree of resemblance between either a mental image or a physical image and the true object it was meant to represent can vary widely because of the differences in the way children assimilate information into their cognitive schemas (Piaget & Inhelder, 1971). In our study, we asked children to ‘draw an engineer doing engineering work.’ The words ‘engineer’ and ‘engineering work’ have socially constructed meanings that are abstract in nature simply because language is a common property of all individuals (Piaget & Inhelder, 1971). Because of this, children will concretize the words ‘engineer’ and ‘engineering work’ by means of their own systems of personal mental images (Piaget & Inhelder, 1971, p. 380). Hence we argue that the children’s drawings are models that show students’ own personal conceptions of “engineers doing engineering work.”

METHODS

Sample

We employed a purposeful sampling strategy (Patton, 2002), using the classrooms of teachers who had participated in a multi-year research study that examined students’ (grades 1–5) conceptions of self and engineering and how these conceptions are shaped by their engagement and learning in various engineering activities (Capobianco, Diefes-Dux, & Habashi, 2009). In this larger project, researchers wanted to learn how students approach, experience, and interact with engineering activities and how their learning informs who students think they are (what community of practice they participate in) and who they want to be (what communities of practice they aspire to). For the purpose of the study reported in this paper, we opted for a sample size that would provide a range of students from two distinct school communities so as to document the similarity, diversity, and/or variation in their conceptions of an engineer. These students represented participants from both the control and treatment groups. All student responses reported in this study were retrieved prior to any intervention.

The Draw An Engineer Test (DAET) was administered to 396 students in 20 classrooms from Grades 1-5 (4 classrooms/grade) in two community settings, including one urban/inner-city school setting in south Michigan and one large, suburban school
community in north central Indiana. The demographics of the entire sample included the following: 201 females and 195 males; 261 White/Caucasian (66%), 67 African American (17%), and 66 Hispanic (17%); and 304 (77%) free-reduced-price lunch. The classrooms represented students from grade 1 (22%), grade 2 (18%), grade 3 (20%), grade 4 (17%), and grade 5 (23%). With the exception of students eligible for free-reduced-price lunch, the demographics in this study aligned reasonably well with the larger U.S. school age population; the national percentage distribution of enrollment in public elementary schools is reported as White/Caucasian (55.8%); African American (17%); Hispanic (21.1%); and free-reduced lunch (42.9%) (Sable & Noel, 2008; U.S. Census Bureau, 2010; U. S. Department of Education, 2010).

Draw-An-Engineer-Test

For the purpose of our study, the Draw-an-Engineer Test (DAET) was intended as an idea-eliciting task. The task itself is an adaptation of a data collection technique first introduced by Chambers (1983), who examined school children's stereotypic views of scientists through drawings - the Draw-a-Scientist Test (DAST). Chamber's DAST was similar to Goodenough's psychological tool entitled Draw a Man Test, but focused specifically on scientists, particularly elementary children's mental images of scientists (Chambers, 1983; Finson, 2009). Chambers argued that a drawing of a scientist made by a child on a blank sheet of paper could be examined to identify specific attributes about the drawing, and, therefore, the child's mental image of a scientist. Finson (2009) suggests that many children's drawings, taken together, could reveal a certain set of attributes students assign to scientists or what Chambers called “stereotypical images.” It became evident, from a psychological perspective, that drawings could certainly reveal significant information about a student's (child's) deeply embedded ideas or mental images (Finson, 2009; Osborne & Freyburg, 1987) without constraining the student to predetermined responses (White & Gunstone, 1992).

The DAET we used in this study was presented on an 8 inches × 11 inches piece of paper. At the top of the paper, students were given the following instructions: “In the space below, draw an engineer doing engineering work.” The space consisted of an empty box (7 inches × 7 inches) for the child to draw his or her image of an engineer. Students were then encouraged to use the space below the box to write their response to the following question: “What is your engineer doing?” In order to ensure a level of quality in all the drawings, teachers gave students approximately 30 minutes to complete their drawings and encouraged them to provide any details, labels, or notes in their drawings.

The DAET evolved from the DAST and has been used only recently within the field of engineering education as a means to assess students’ ideas about engineering, engineers, and designers at the elementary (Knight & Cunningham, 2004; Oware, Capobianco, & Diefes-Dux, 2007), secondary (Frailick, Kearns, Thompson, & Lyons, 2009; Lyons & Thompson, 2006), and undergraduate levels (Lande & Leifer, 2009). Underpinning these studies is the universal search for students to show what they hold as the most important characteristics, ideas, perceptions, and knowledge about engineers and engineering.

Data Collection

The DAET was administered to students in 20 classrooms from Grades 1-5 (4 classrooms/grade) in the two community settings in September and October 2009, respectively (total = 396 drawings). Students completed the DAET during their regularly scheduled science time. Each teacher was familiar with the drawing test and its administration. The
teachers were provided written directions describing the procedures for administering the drawing test. The test was administered by the teachers prior to any classroom instruction on the topics and activities related to engineering and engineering education.

Of the 396 students, four students per classroom for each grade in each school (total = 80 interviews) were interviewed as a means of examining critically what students drew and how they represented their ideas, thoughts, and conceptions (Fraser, Lewis, Ding, Kellett, & Robinson, 2004). Each student was interviewed individually by members of the research team after the DAET was administered. Each interview began with the interviewer asking the student to look at his or her drawing and talk aloud about what he/she drew. Examples of interview questions included the following: “Tell me about your drawing.” “Is your engineer a boy or a girl?” “What is the engineer doing? What can you tell me about this person?” “Can you complete the following sentence starter for me? An engineer is someone who...” The interviews were audio-taped and transcribed by members of the research team. Short notes about what had happened were recorded both during and immediately after the interviews.

Data Analysis

Data analysis involved two phases. The first phase involved a content analysis of students’ responses resulting in the identification of students’ conceptions in the DAETs and interviews, and this process was inductive in nature (Krippendorf, 2003). The second phase involved the statistical testing of differences in frequency of the identified conceptions across grades and community. These two phases of analysis are described in detail below.

Content Analysis

The interpretive nature of the DAET and interview required an inductive approach; that is, instead of searching for predetermined patterns, themes were allowed to emerge from the data as the researchers constructed meaning from students’ responses (Patton, 2002). The first step entailed the reading and re-reading of all drawings then interview transcripts. From this first series of readings, core concepts (codes) were identified among all of the drawings. These codes were then triangulated with codes identified among the interview transcripts. For example, a drawing that included a person positioned under a car accompanied by the following text: “The engineer is fixing the car” was coded in the following manner: ACTN - FIX (action is fix), ART - CAR (artifact is a car). If a student described the engineer in his or her drawing during an interview as “Someone who fixes the heater and air conditioner in the house,” it was coded in the following manner: ACTN - FIX, ART - HEATR, ART - ELECTRICS. These initial codes were revised after a second reading. Descriptive themes were then constructed using the codes across different grade levels and community settings. Codes with common/overlapping themes were subsequently placed into categories that reflected the students’ conceptions. Each researcher independently grouped the codes into individual categories. Examples of these categories included MECH (mechanic), LABR (laborer), and TECH (technician). From these individual category matrices, we constructed a group-consensus category matrix that linked each code to a category (Erickson, 1986; Miles & Huberman, 1994) and that reflected the final categories of student conceptions about engineers (see Results: Table 1). This process of independently constructing categories and then reaching group consensus provided a degree of triangulation, reducing the influence of bias and subjectivity, and increasing
validity of our analysis and interpretation of the results (Lincoln & Guba, 1985; Patton, 2002; Strauss, 1987).

Students’ conceptions were triangulated across different grade levels, school communities, and across the two data sources. To ensure consistency in coding, an inter-rater reliability coefficient was calculated by comparing four researchers’ coding of 10 randomly selected DAETs. The inter-rater reliability coefficient for the task was .89. Coding was monitored throughout to ensure consistency and reliability.

**Statistical Analysis.** We employed the chi-square test to determine whether the frequencies of student responses differed from what we would have suspected by chance alone. We compared the frequency of the conceptions across grade-level classrooms and school community settings to determine the stability of the conceptions using a $5 \times 2$ matrix (number of grade levels X number of school community settings). There were five grade levels (Grades 1 through 5) with two classrooms per grade level for each of two school community settings (urban and suburban). This initial chi-square test allowed us to examine whether the identified conceptions appeared consistently across different grade levels and school settings.

**RESULTS**

We first present the results of our inductive analysis, identifying the four emergent themes that reflected students’ perceptions. Next, we report the results of our statistical analysis of the distribution of students’ perceptions across different data sets: grade level, gender, and community setting.

<p>| TABLE 1 |</p>
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<th>Conceptions and Elements of Each Conception for Grades 1-5 DAETs</th>
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Students’ Conceptions of an Engineer

From the inductive analysis, we identified codes (characteristics) that reflected students’ responses on the Draw an Engineer Task (DAET) and interview. These codes were grouped into two central domains represented in each drawing and in each student’s response to the question stated below the drawing, “What is the engineer doing?” as well as students’ responses to interview questions. These codes included the following: (1) actions performed by an engineer (e.g., building) and (2) artifacts (or objects) used by an engineer (e.g., engine). The codes were grouped based on recurring patterns that reflected four distinct categories of characteristics students assigned to an engineer.

- **Conception 1**: An engineer is a mechanic who fixes engines or drives cars and trucks.
- **Conception 2**: An engineer is a laborer who fixes, builds, or makes buildings, roads, and other structures.
- **Conception 3**: An engineer is a technician who fixes electronics and computers.
- **Conception 4**: An engineer is someone who designs.

Three of the conceptions depict an engineer as a person who fixes, builds, or works with engines, vehicles, buildings, or electronics. The complexity of students’ ideas varies across conceptions, with Conceptions 1, 2, and 3 representing simplistic and literal meanings assigned to an engineer. One signature similarity among three of the four conceptions was the identification or presence of an object being “fixed.” Conception 4 was uniquely different from the other conceptions based on the abstract nature of design. Each of these conceptions is explained below and depicted in Table 1. This table provides a visual matrix of the varying characteristics students assigned for each conception.

**Conception 1: An engineer is a mechanic who fixes engines or drives cars and trucks.** For these students an engineer is a person who repairs, works on, or drives an array of vehicles, including cars, trucks, trains, and airplanes. Much of the actions described by students in their drawings and interviews involved an engineer performing manual, physical, or mechanical labor, such as working under a car, under the hood of a car, or driving a train or plane. One fifth grader wrote below her drawing that the engineer was “…fixing a car that broke down…” (Serena, Grade 5). Her conception that an engineer is a mechanic was confirmed in her interview when she described the engineer in her drawing as “…the engineer is at his car repair shop” (Serena, Grade 5). As shown in Figure 1, student responses often represented a person next to a vehicle. In some cases, particularly among younger student responses, the engineer was depicted not as a person but as an object, an engine.

**Conception 2: An engineer is a laborer who fixes, builds, or makes buildings, roads, and other objects.** What differentiates this conception from Conception 1 is the emphasis on the actions and artifacts the engineer uses. Student responses illustrated a skilled laborer—plumber or carpenter. When interviewed, one second grader, who drew a person working under a sink, stated that an engineer is someone who “…has to go everywhere to fix sinks and everything else… fix anything that moves, fix anything in the bathroom, your toilet, your bathtub” (Addison, Grade 2). Students’ written and oral explanations reinforce the connections drawn between the tradesmen and the artifacts they work with on a regular basis (Figure 2).

**Conception 3: An engineer is a technician who fixes electronics and computers.** Student responses in this category, like the one shown in Figure 3, emphasized the practical skills of a person who works directly with electronics and electricity (e.g., computers,
FIGURE 1. Example of an engineer as a mechanic drawn by a male student in grade 3.

FIGURE 2. Examples of an engineer as laborer drawn by a female student in Grade 2 and male student in Grade 2, respectively.
software, telephones, or televisions). Like Conception 2, this conception implies the notion of the person having or using technical skills to do their job. Similarly, as shown in Figure 2, student responses often represented a person working with particular artifacts, such as discrete tools (e.g., wrench, measuring tape, or screwdriver) and supplies (e.g., wire, software, or cords).

Conception 4: An engineer is someone who designs. Conception 4 is an interesting case because an engineer is characterized as a “designer” among a limited number of fourth and fifth grade students, only 17%. Most times, students used the same artifacts that appeared in the previous conceptions, but the action of “fixing” was changed to “designing.” That is, engineers were depicted as designing cars, buildings, and electronic devices. They were also portrayed as designing circuits and computer software. One fifth grade student drew an image of an engineer working on a robot (Keegan, Grade 5), while another fifth grade student drew an image of an engineer at a computer station (Lara, Grade 5). Students’ drawings of engineers as designers were confirmed by interview data. In their interviews, students characterized an engineer as “… a person who designs and creates things” (Keegan, Grade 5) or “someone who is designing something…making it and then seeing if it will work by testing it” (Lara, Grade 5). One of the students described his drawing of an engineer working on a robot from a futuristic perspective by stating that “He is designing a maid robot for people who are… in their 70 or 60s … and need help around their house and stuff” (Keegan, Grade 5, interview). This is an important characterization from the standpoint that the engineer is not only designing something but that the object (robot) is serving a purpose or need (help cleaning the house) for a specific client or user (an older adult).

Outliers. We use the term “outliers” to represent students’ conceptions of engineers that occurred less often or infrequently. This includes isolated references to professionals, such as police officers, firemen, teachers, veterinarians, and physicians (n = 11%). We speculate that children, in this case, are drawing images of professionals who they interact with often and hold intimate knowledge of as a result.

Descriptive Statistics

The percentages of drawings representing each conception at each grade 1 to 5 are shown in Figure 5. Because some students portrayed more than one conception, and other students did not portray any conception, the total number of conceptions may not be equal to the total number of students. The dominant conception elicited at each grade level was Conception 1, a literal representation of the word “engine” and actions taken on an engine such as “fix.” This conception reflects a word-meaning association wherein students’ prior experiences and knowledge about the terms “engine” and “fix” are used to make meaning of the work of an engineer. It reflects the engineer working as a mechanic who fixes cars. This conception accounted for 46% of the total sample. Approximately 19% of students conceptualized an engineer as a laborer who also fixes, builds, and makes structures such as roads, houses, and buildings or objects, including toys, toothbrushes, and sinks (Conception 2). These students situate the engineer as someone who manually or physically constructs and assembles both large and small structures and/or objects. Of the remaining students, 7% conceptualized an engineer as a technician (Conception 3), and 6% conceptualized an engineer as a designer (Conception 4).

Based on chi-square results presented in Table 2, it appears that there is a significant difference by grade level for Conception 2 (Laborer) (p < .05). This coincides with the
FIGURE 3. Example of an engineer as a technician drawn by a female student in grade 3.

FIGURE 4. Example of an engineer as someone who designs drawn by a female student in grade 5.
data presented in Figure 5 that shows variation by grade, more specifically, higher percentages of Conception 2 from students in grades 1, 2, and 5 but lower percentages in grades 3 and 4. The remaining Conceptions 1 (Mechanic), 3 (Technician), and 4 (Designer) did not demonstrate statistically significant differences, although Mechanic came close.

There is also a significant difference by community setting for Conception 3 (Technician) \((p < .01)\). Based on Figures 6 and 7, it appears that students from the suburban community classrooms reported higher percentages than students from the urban community classrooms. While other conceptions did not show statistically significant differences by community, Conception 2 (Laborer) came close. In sum, these results indicate that there are some significant differences by grade and community. However, the frequencies of most students’ conceptions are relatively consistent across all 20 grade-level classrooms.

**Engineer conceptions by grade level and community setting.** The percentage of each conception by community setting is shown in Figure 6. The percentage of students who drew Conception 1 (mechanic) in the urban/inner city community was approximately the same as the percentage of students in the suburban community (46%, 49% respectively). A greater percentage of students from the urban community (20%) conceptualized an engineer as a laborer (Conception 2) compared to the percentage of students from the suburban community (8%). Conversely, a greater percentage of students from the suburban community (24%) conceptualized an engineer as a technician (Conception 3) compared to the percentage of students from the urban community (7%). This may reflect conditions of the current job market for each respective community and the types of jobs or occupations family members hold.

Figures 7 and 8 illustrate students’ conceptions of an engineer by grade level and community setting. A slightly greater percentage of Grade 3 and 4 students (55%, 51% respectively) conceptualized an engineer as a mechanic compared to the percentage of Grade 1, 2, and 5 students (43%, 46%, 44%, respectively). On the other hand, a slightly greater percentage of Grade 1, 2, and 5 students (30%, 32%, 27% respectively) conceptualized an engineer...
as a laborer compared to the percentage of Grade 3 and 4 students (10%, 14% respectively). These findings suggest that Grade 3 and 4 students are confusing the work of an engineer to that of a mechanic, and, in some cases, using the root word “engine” as a term associated with the work of an engineer. They linked the word engine to concrete objects or specific individuals. In the case of Grade 1, 2, and 5 students, they conceptualized an engineer as a laborer (e.g., plumber, carpenter) who works with these objects and is someone who students are familiar with in their everyday lives. Thus, everyday language guided these students’ conceptual constructions (Duit, 1991) and how they represented their conceptions of an engineer as a mechanic or laborer.

**Engineer conceptions by grade level and gender.** Figure 9 illustrates the percentage of students who drew male versus female engineers. Overall, approximately 58% of students drew male engineers, and 18% drew female engineers. The rest of the students (24%) either drew groups of engineers, or engineers with no gender features, where it was not possible to assign a gender. The greatest percentage of students who drew male engineers were Grade 5 students (70%).

In addition to determining which gender was represented in students’ conceptions, we also examined which students (girls and boys) were drawing male vs. female engineers. We were curious to see if there was a pattern across the grades with regard to exactly which students were drawing male engineers and which students were drawing female engineers. Figure 10 represents the percentage of girls who drew male vs. female engineers. Figure 11 represents the percentage of boys who drew male vs. female engineers. While most students drew male engineers, students who drew female engineers were mostly female students. In fact, only male students in grade 3 drew female engineers; no male students in grades 1, 2, 4, or 5 drew females.

These findings may suggest elementary school students associate the conception of an engineer as a predominantly male figure. Previous studies in engineering education have noted that engineering is among the most strongly gender-stereotyped of occupations (White & White, 2006). A stereotype can be learned very early in life and play a major role in shaping a child’s understanding of an occupation (Campbell, 1967; Egan, 1978). Stereotyping amounts to a generalization about the traits and behaviors of a group including an occupational group such as scientists and engineers (Holbrook, Panozza, & Prieto, 2009). Koblinsky, Cruse and Sugawara (1978, p. 452) referred to the “constellation of generalized

### Table 2
Chi-Square Results, Conceptions by Grade Level and Community Setting

<table>
<thead>
<tr>
<th>Conception</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanic</td>
<td>$x^2 = 5.21$</td>
<td>$x^2 = 6.14$</td>
<td>$x^2 = 1.46$</td>
<td>$x^2 = 2.09$</td>
</tr>
<tr>
<td>Laborer</td>
<td>$p = .067$</td>
<td>$p = .036$</td>
<td>$p = .476$</td>
<td>$p = .312$</td>
</tr>
<tr>
<td>Technician</td>
<td>$x^2 = 4.11$</td>
<td>$x^2 = 5.06$</td>
<td>$x^2 = 9.12$</td>
<td>$x^2 = 3.07$</td>
</tr>
<tr>
<td>Designer</td>
<td>$p = .121$</td>
<td>$p = .078$</td>
<td>$p = .007$</td>
<td>$p = .223$</td>
</tr>
<tr>
<td>Community setting</td>
<td>$x^2 = 4.11$</td>
<td>$x^2 = 5.06$</td>
<td>$x^2 = 9.12$</td>
<td>$x^2 = 3.07$</td>
</tr>
<tr>
<td>$p = .121$</td>
<td>$p = .078$</td>
<td>$p = .007$</td>
<td>$p = .223$</td>
<td></td>
</tr>
</tbody>
</table>

100 (April 2011) 2 Journal of Engineering Education
expectations when studying the manifestation of sex role stereotypes in young children and noted that this level of oversimplification can ultimately restrict life options. According to Holbrook, Panozza, and Prieto (2009), the more abstract the occupation is in reality (and here engineering fits the description as few can effectively describe the range of sub-occupations that constitute engineering) the more vulnerable it is to stereotyping. While students in this study demonstrate a trend in characterizing an engineer as predominantly male, we cannot fully assert that their conceptions are clearly defined gender-stereotypes. Further research on students’ conceptions and gender assignments in engineering is warranted.

FIGURE 6. Conceptions of engineers by community setting.

FIGURE 7. Conceptions of an engineer by grade and urban school community setting.
DISCUSSION

Based on our review of students’ drawings and interviews, we interpret students’ conceptions of an engineer as contextually framed and socially influenced. Students used words and mental images to interpret their own world, their experiences (both in and out of the classroom), and more importantly, their view of an engineer. When hearing the term “engineer,” students associated this term with the core word “engine” and therefore assigned existing conceptions of engine to an engineer. For example, when we instructed students such as Tasha (Grade 2), Michael (Grade 3), and Lisa (Grade 4) to point to the

FIGURE 8. Conceptions of an engineer by grade and suburban community setting.

FIGURE 9. Conceptions of male versus female engineers by grade.
engineer in his or her drawing, he or she pointed to the car's engine. When we probed further by asking what does this engineer do, students talked about the engineer fixing, helping, or repairing. For example Tasha described in her interview that her engineer was someone who “fixes engines” (Tasha, Grade 2, interview). Michael described an engineer as someone “who repairs cars and fixes engines” (Michael, Grade 3, interview), and Lisa described an engineer as someone who “helps people with their cars like my dad” (Lisa, Grade 4, interview). In short, the engine was no longer an object but a figure or person that
performed specific tasks. In this case, students’ conceptions were represented by both mental and physical images (Piaget & Inhelder, 1971). Students in this study have assimilated a mental image or cognitive schema of an engineer as a physical image (e.g., engine). When we interviewed students, we listened to students’ anecdotes of learning about engineering from a father (e.g., Lisa, Grade 4), grandfather, or uncle who “fixed,” “built,” or “repaired” cars, trucks, or trains. Vygotsky (1987, 1991) argued that language itself defines and limits our thinking, just as our past experiences influence the way we view and interpret present and future experiences.

Students’ conceptualizations of an engineer were also grounded in the notion that an engineer is predominantly male. As previously stated, our aim in this study is not to determine the nature of students’ conceptions. However, during the course of our analysis, we questioned if elementary school students held occupational stereotypes about engineers and whether these stereotypes were formed early in the course of the students’ socialization. Although this pattern in gender assignment by students in this study was more pronounced among Grade 4 and 5 students, it was quite apparent as early as Grade 2. Our conjecture is that very young children may be exposed to images of an engineer by different socializing agents (e.g., parents, peers, and teachers) and these images may be inaccurate and, in some cases, unrealistic.

Students’ Conceptions and Curriculum

There is a need for schools to develop students’ conceptions of engineers within curricular frameworks (NAE, 2004, 2008; NAE & NRC, 2009). Designing a curriculum based on students’ conceptions that builds toward a more accurate, informed perspective is essential (NAE, 2009; Singer, Marx, Krajcik, & Chambers, 2000) if students are to become more knowledgeable about and interested in engineering-related issues, challenges, and/or careers.

Building on the findings from this study, we draw from current reform initiatives in engineering education (NAE, 2008; NAE & NRC, 2009) and existing research on young students’ conceptions of engineers (Capobianco, Diefes-Dux, & Habashi, 2009; Cunningham et al., 2005; Oware et al., 2007) to propose what we refer to as key attributes of an engineer. The following attributes need to be developed in order to both inform and enhance elementary school students’ conceptualization of an engineer.

An engineer is someone who…
• is creative
• uses science
• uses mathematics
• uses technology
• works in teams
• designs everything around us
• solves problems to help people

We characterized the engineer as having key qualities that transcend multiple fields of engineering. By doing so, we clarify key aspects of the engineer’s work, set this work apart from other professions (e.g., the work of a scientist), and provide a consistent and cohesive conception for practitioners to incorporate into their own practice. In addition, this framework allows students to identify with one or more attributes and potentially build interest, confidence, and participation in engineering by envisioning themselves as possessing and/or practicing these particular attributes.
Connecting the Standards and the Engineer Concept

By integrating these attributes, engineering educators (e.g., educational researchers, curriculum specialists, and practitioners) can begin to develop interdisciplinary and thematic curriculum through which students learn about the work, skills, and attributes of engineers and apply their newly acquired understandings to their own engagement in engineering activities. Supplemented by corresponding benchmarks from the NRC (1996) National Science Education Standards [NSES] and the ISTE (2007) National Educational Technology Standards [NETS], educators can create standards-based curriculum grounded in the engineer concept and supported by both engineering design and scientific inquiry skills. For example, the NRC’s Content Standard E - Science and Technology provides a feasible entry point for developing curriculum connections with key attributes of the engineer concept. The Content Standard E for students in grades K-4 and grades 5-8 states: “…all students should develop: 1) abilities of technological design; 2) understanding about science and technology; and 3) abilities to distinguish between natural objects and objects made by humans [K-4 only]” (1996, p. 135; 161 respectively). The NETS Standard 4 - Critical Thinking, Problem Solving, and Decision Making states: “Students use critical thinking skills to plan and conduct research, manage projects, solve problems, and make informed decisions using appropriate digital tools and resources” (2007, p. 12). Underlying these standards are fundamental abilities and concepts students must know, apply, and understand. Students must be able to identify a problem; design a solution or product; and implement, evaluate, and communicate the solution or product (ISTE, 2007; NRC, 1996).

These standards emphasize students’ ability to design a solution to a problem and to understand the relationship of science and technology and the way people are involved in both. According to the NRC, “this standard [Content Standard E] helps establish design as the technological parallel to inquiry in science. Like the science as inquiry standard, this standard begins the understanding of the design process, as well as the ability to solve simple design problems” (1996, p. 135). Hence, these standards intersect with three key dimensions that align well with the engineer concept. The first dimension is the practice of problem solving. Students must recognize a problem; identify and implement possible solutions; work within constraints; and construct and evaluate a model, prototype, or artifact. The second dimension is the sociocultural aspect. Students, like engineers, must be able to work in teams, collaboratively make decisions, and communicate ideas within and across teams. The last dimension entails access to scientific and technological knowledge, skills, and tools. Students may find that they need to use different sources of knowledge in addition to scientific conceptual understandings. This includes knowledge such as cost, risk, and benefit analysis; particular skills such as critical thinking and creativity; and appropriate tools (e.g., scientific and technological) in order to advance in design challenges or learning activities.

The NRC and ISTE further recommend that students at the elementary school level should be given opportunities to develop firsthand experiences in tackling practical tasks that both challenge them developmentally and also provide a familiar context (e.g., home and school) for them to learn. This includes authentic learning tasks that may allow teams of students to study technological products and systems in their world (e.g., zippers, toothbrushes, can openers, or bridges). By doing so, student learning is situated within the context of real world problems (Brown, Collins, & Duguid, 1989) that allow students to collectively build a community of practice (Lave & Wenger, 1991) and construct more informed conceptualizations of an engineer.
The examples we profiled in this section demonstrate that the development of a curriculum grounded in the engineer concept can provide opportunities for students and teachers to explore and analyze the world from a technological and design-informed perspective rather than discrete, isolated segments. Thinking about the work of engineers in a holistic, authentic, and practical manner creates a meaningful context for learning and doing engineering because it requires that students use and apply concepts, principles, and skills from science and technology.

**CONCLUSION AND IMPLICATIONS**

Students in this study primarily conceptualized an engineer as a mechanic, laborer, and technician. According to student interviews and drawings, the engineer was restricted to fixing, building, making, or working and using artifacts such as vehicles (e.g., cars, trucks), engines, buildings, and tools (e.g., wrenches, hammer). Additionally, both male and female students in this study assigned gender-stereotypes to their respective drawings and working conceptions. The purpose of this study was to elucidate students’ conceptions of an engineer; it was not an attempt to identify or articulate the origin or development of students’ conceptualizations. Nor was this an attempt to report on a quasi-experimental study of students’ conceptualizations before and after engaging in engineering-related activities. Thus, there is a need for future research to determine the role of students’ experience and education in shaping the development of their conceptions. Do individual students develop different conceptions over time? In what ways does social interaction among peers, teachers, and parents influence the development of a student’s conceptualization of an engineer? How might a parent who is a professional engineer influence his or her child’s conceptualization of an engineer? Although this study separated students’ conceptions by grade level, gender, and community setting, there is a need to investigate students’ conceptions by age, culture, and socioeconomic conditions. Longitudinal studies of students’ developing conceptions would also be useful in determining the impact of experience and schooling on students’ conceptualization of an engineer. How does engaging in engineering learning activities impact students’ conceptualizations of an engineer? Finally, there is a need to understand the relationship between students’ conceptions and their educational experiences and career-decision making.

Unique to our study is the combined effort of capturing students’ conceptions via visual data from drawings and verbal data from individual student interviews. Integrating the use of visual data is both productive and informative for university researchers and K–12 practitioners alike (Finson, 2009). Depending on the researchers’ needs, visual data can elicit more from participants than what can be captured with more traditional data collection methodologies (Kearney, 2009). Drawings can also confirm other verbal reports, field observations, and supporting documents (Pedersen & Finson, 2009). For K–12 practitioners who incorporate engineering education ideas in their classrooms, visual data can serve as a form of formative and summative assessment. The DAET, for example, can be used before and after a professional engineer visits an elementary school classroom. Practitioners can review students’ drawings and identify possible changes in what the engineer is doing, what artifacts are being used, or new terminology students use in their descriptions. Additionally, insight gleaned from students’ drawings can also lead practitioners to decide whether or not there is a need for inviting female engineers to their classrooms as role models, and a need to help students learn about the profession of engineering, in general. This, in turn, can serve as a starting point for a new and innovative engineering curriculum, grounded in our engineer
model, whereby practitioners develop, implement, and assess students’ conceptions over the course of multiple design-based learning activities or units. Comparing these drawings with earlier ones can provide insight into what students learned and if their conceptions of an engineer shifted. It should be noted that this is one of many different ways practitioners can use the DAET to elicit students’ conceptions and that consideration must be given to providing children with multiple opportunities to express their ideas through visual data.

As a result of our examination of students’ conceptualizations of an engineer, we developed an analytic framework for organizing and interpreting students’ conceptions. Researchers may find this framework useful in categorizing and orienting students’ conceptualizations of phenomena such as the engineer, engineering, and technology. In addition, we provided three key dimensions of the engineer concept that were supported by the NRC National Science Education Standards and the ISTE National Educational Technology Standards. These dimensions may help researchers and practitioners investigate the potential impact their respective curricular interventions may have on students’ conceptualizations. We conclude by stating that the integration of engineering curriculum in the elementary classroom continues to be a novel, uncharted endeavor. It is critically important that researchers and practitioners of engineering education rethink how they go about developing, implementing, and assessing engineering curriculum in the elementary (and possibly K-12) classroom. Equally important is the need for researchers and practitioners to gather students’ prior knowledge, i.e., existing conceptions, and design curriculum that builds upon students’ ideas, needs, and interests. This paper provides effective mechanisms to help researchers and practitioners: (1) identify, analyze, and interpret students’ existing conceptualizations of the engineer; (2) develop, integrate, and assess standards-based engineering curriculum; and (3) investigate the impact of this curriculum (and other interventions) on student learning of engineering.

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