

Fundamental Research: Developing a Rubric to Assess Children's Drawings of an Engineer at Work

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I have had more than 15 years of experience in the fields of structural and concrete materials engineering. I have worked as an engineer with a design consultant, construction contractor, government agency, and as a professor. I feel that my practical experience has made me a better teacher and researcher. I enjoy teaching, and regularly receive positive feedback and evaluations from my students (3.86/4 average rating as an instructor). I was also fortunate to be awarded the Halliburton Excellent Young Teaching Award in 2011, the Williams Foundation Professor in 2013 for the College of Engineering, the ACI Walter P. Moore Faculty Achievement Award in 2014, the Researcher of the Year Award from the College of Engineering in 2014, Halliburton Excellent Young Professor in 2014, and the OSU Regents Research Award in 2014.

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Developing a Rubric to Assess Children's Drawings of an Engineer at Work

Abstract

Research in elementary engineering education focuses on the ways a developing body of curricula enhances children's conceptions of engineers. To this effort, researchers have focused on exploring children's knowledge, interests, and attitudes related to the work of an engineer. Given that currently available measurement instruments are defined by check-lists, we hoped to expand available assessments to include a research-based tool to measure children's conceptual understanding about the work of an engineer. The purpose of this research study was to develop a way to assess children's drawings of engineers at work. Specifically, we wondered: What defines the varied range of children's contextual understanding about the work of an engineer as it relates to applied science and mathematics? Research efforts were informed by others' work with children's drawing prompts: the *Draw-a-Scientist Test* (DAST) and the *Draw-an-Engineer Test* (DAET). Grounded theory methods guided our query about how 4th and 5th grade students (from rural, Midwestern schools) described their knowledge and understanding about the work of an engineer. Our data consisted of children's drawings (n=940) of engineers at work and written explanations about the engineer's gender, work effort, and applications of science and mathematics. Data were analyzed by seven researchers through a constant comparison of data. The resulting theoretical propositions were organized into a rubric that captures the continuum of children's understanding about the work of engineers. Here we describe the development and controlled application our draw-an-engineer assessment tool. The rubric and scoring guide (to manage inter-rater reliability and insure objectivity) will be defined in a future manuscript.

Introduction

Research in elementary engineering education follows on broad interest in equipping students with 21st Century knowledge and skills and specific concern for raising awareness and interest in engineering careers.¹ Generally, K-12 engineering education initiatives intend to inspire students' career awareness and interest with the hope of increasing the numbers of engineers and diversifying the career pipeline. In 2009, the Committee on K-12 Engineering Education raised concern for the "paucity of data" (p. 154) regarding impact of current programs. To guide future engineering education curricula development and program assessment, the Committee identified three guiding principles. According to these recommendations² engineering education should 1) emphasize engineering design; 2) incorporate important and developmentally appropriate mathematics, science, and technology knowledge and skills; and 3) promote engineering "habits of mind."

The majority of research studies focus on measureable outcomes of K-12 engineering education programs. Some have focused on enhanced engineering career awareness.^{3,4} Others have focused on increased understanding of engineering design principles.^{5,6} Yet others have focused on increased awareness of the ways engineers apply science and mathematics functions and procedures.⁷ In all, these assessments of children's increased knowledge and awareness have

largely focused on defining children's knowledge, interests, and attitudes related to the work of an engineer.

We understand early elementary experiences are foundational to children's later attitudes about and interest in science and mathematics⁸ and expect that elementary engineering education assessment may provide further understanding about early formation of STEM career pipelines and guide researchers' and educators' evidence-based interventions. Given that currently available elementary engineering assessment instruments are largely defined by check-lists and other closed-ended instruments, it is essential to expand the available resources to include research-based tools to measure children's conceptual understanding about the work of an engineer. We began this research with the idea of creating a rubric to organize scoring rubric to capture the wealth of data children provide when they are asked to "draw an engineer."

Influential Assessments and Sample Prompts

Our research efforts were informed by two lines of research stemming from others' work with children's drawing prompts. These include the *Draw-a-Scientist Test* (DAST)⁹ and the *Draw-an-Engineer Test* (DAET).¹⁰ While some of the same ideas apply, our protocol and rubric might be viewed as an expanded combination of the DAST and the DAET.

Draw-a-Scientist Test (DAST). The *Draw a Science Test* introduced by Chambers⁹ followed his interest in the development of children's stereotypical notions of scientists. In this test, children were given a blank piece of paper and prompted to "draw a scientist." Chambers argued these images of a scientist portrayed children's mental image of a scientist. Others reasoned that, from a psychological perspective, these drawings provide an unconstrained image¹¹ of children's deeply embedded ideas about a scientist.^{12,13} Finson, Beaver, and Crammond¹⁴ later developed the Draw a Scientist Test Checklist (DAST-C) which added a scoring list to the DAST to help track all aspects and features of children's illustration of a scientist: appearance, location, and activity. This checklist of items, however, continued the limited function of assessing the stereo-typicality of children's images (the more items checked, the more stereotypic the child's drawing). Barman¹⁵ and Chambers⁹ learned that, when asked to talk about their picture of a scientist, children were able to verbalize more detailed understanding about the work of a scientist. Thus, the cataloging of children's single image of scientists further limited conveyance of children's ideas.

Draw-an-Engineer Test (DAET). The *Draw an Engineer Test*¹⁰ was developed as a modification to the DAST. In a similar test administration, children were given a blank sheet of paper (divided into two sections). In the top space, children were prompted to, "Draw an engineer doing engineering work." In the bottom space, children were asked to explain their drawing: "What is your engineer doing?" As with Chambers'⁹ effort, Capobianco et al.¹⁰ sought universal understanding of what students hold as most important to the nature and work of engineers and engineering. Researchers at the National Center for Technological Literacy²¹ administered the DAET to some 900 K-12 students adding a prompt: "What is technology?" While they were disappointed their data was not conducive to quantitative analysis, they were able to draw on DAET findings to develop a set of instruments and systematically probe student conceptions. These instruments include the following:

1. *What is Technology?*¹⁷ measures changes in students' understanding of the human-designed world. Here children are asked to distinguish between natural and human-made items by selecting examples of technology from 20 provided images.
2. *What is an Engineer?*¹⁰ gauges changes in children's understanding of the work of engineers. Here children are prompted to identify the work of an engineer from a list of design-based activities an engineer might do at work (e.g. "develop smaller cell phones" or "improve camera lens"), as well as non-design activities that engineers do not do at work (e.g. "fix computers" or "repair cars").
3. The *Engineering Attitudes* questionnaire¹⁸ prompts children to rank their engineering attitudes and job interests [Likert-type items ranging from strongly disagree to strongly agree]. This questionnaire asks about children's perceived value of science and math and includes a twenty-item engineering attitude sub-scale and a nine-item job-interest subscale with nine items along three interest dimensions: (a) Invent (jobs and activities that involve inventing and building/designing cars and buildings); (b) Help (jobs and activities that involve helping people and the environment; and (c) Figure Things Out (jobs and activities that involve figuring out how things work). Questions about engineering career attitudes included items such as, "I would enjoy being an engineer when I grow up" and "Engineers help make people's lives better".

Modified Draw-a-Scientist Test (mDAST). While the DAST and DAET drew from relatively simple "draw a scientist" or "draw an engineer" prompts, they enabled the first open-ended consideration of children's conceptions and a healthy review of the attributes generated. More recently, Farland-Smith¹⁹ envisioned the *modified Draw a Scientist* (mDAST). This new protocol expanded the "draw a scientist" test to include three drawings of a scientist and added prompts for speech balloons and other explanatory narrative details. On an additional page, students were prompted to indicate if their scientist was a man or woman; where the scientist was working; and what the scientist was doing. Taken together, these drawings and narrative details, allowed Farland-Smith to create an mDAST rubric that organizes a scoring rubric continuum ranging from "sensationalized" to "traditional" to broader than traditional" (p. 111).¹⁹ As she explained, ". . . this assessment is easy to administer and score and it can be used in a multidimensional manner that was more difficult with the . . . DAST-C" (p. 115).¹⁹ Farland-Smith was the first to consider children's thinking on a continuum (from limited to advanced understanding) and to organize a scoring rubric to guide the ranking of these illustrations. These scores newly allowed for increased detail about children's mental images and quantitative analysis of children's conceptions beyond a list of stereotypical attributes.

With this research study, we sought to expand upon the DAST and DAET procedures to create an assessment rubric that captures the continuum of children's understanding about the work of engineers. Specifically, we wondered: What defines the varied range of children's conceptual understanding about the work of an engineer as it relates to applied science and mathematics? In this paper, we describe the development and controlled application of a draw-an-engineer assessment rubric. The rubric and scoring guide (to manage inter-rater reliability and insure objectivity) will be defined in a future manuscript.

Expectancy-Value Theory

Expectancy-value theory guided our thoughts about linking children's conceptions about the work of an engineer to children's understanding of the ways in which engineers use or apply

scientific or mathematical tools or processes. According to expectancy-value theory, children's motivation, achievement and persistence in an academic area is primarily influenced by two things: *expectancy for success* and *subjective task value*. It has been a relatively consistent finding that expectation for success (confidence or self-efficacy) will predict children's achievement, while subjective task value (usefulness or enjoyableness) will predict children's persistence and selection in any given subject.²⁰

In one application, Simpkins et al.²¹ explored the relationship between students' interest and persistence in science classes and students' interest and understanding of science careers. Researchers concluded science activity predicted expectancy and subjective task value (confident students also considered science careers) and proposed that exposure might increase motivation. We expect then, that a measure of children's contextualized understanding of science and mathematics component to the design work of an engineer, will add to our understanding about children's consideration of engineering as a career option. As Fung²² noted, these measures of children's perceptions are critically important to helping insure their pursuit of advanced studies along a path to engineering careers.

Methods

We followed grounded theory methods to examine how students described their knowledge and understanding about the work of an engineer. Our data consisted of 4th and 5th grade children's drawings of engineers and written explanations about the engineer's gender, work effort, and applications of science and mathematics. We expected these records of children's conceptions would help us derive theoretical propositions (in the form of an evaluation rubric) about children's conceptions of engineering, grounded in the views and language of these participants.

Procedure. Student participants were given one legal-sized piece of paper that was divided into thirds (horizontally). Students were asked to "draw an engineer at work" in each frame and to answer three questions about each illustration: 1) Is the engineer male or female?; 2) How is the engineer using math?; and 3) How is the engineer using science? Finally, students were asked to add a speech balloon (to show us what the engineer is thinking or saying) and to write a sentence about the engineer's work. Our protocol for the Modified Draw an Engineer Test (mDAET) incorporated essential understanding drawn from the DAET. It was, however, different in two ways. In the first difference, following on the details of the mDAST,¹⁹ the mDAET also prompted students to add an illustration and a comment (or speech balloon) to further detail their understanding of an engineer's work.

We engaged in reciprocal steps of data collection and analysis of data to allow emerging categories and theoretical sampling of children's language to determine the varying levels of conceptual understanding across participant responses.^{23,24} That is, we allowed children's illustrations and explanations to construct our theoretical propositions about their conceptual understanding. As we worked, we continuously coded the data, categorized it, and integrated the big ideas into a scoring rubric for testing and verification. We followed open coding procedures^{23,24} to analyze, label, and organize discrete ideas into categories of conceptual understanding and levels of development along a continuum. Open coding and development of a rubric similar to the draw-a-scientist rubric¹⁹ guided organization of these categories into a

continuum of developmental levels (from naïve or basic to advanced conceptions) growing increasingly more sophisticated and complex.

Verification. We followed Miles and Huberman's²⁵ multiple procedures to verify our data. Recognizing our likely bias as science, mathematics, and engineering researchers (objectivity), we met regularly to insure high inter-rater consistency among the researchers and graduate research assistants over time (dependability). Eight researchers participated in continuous hypothesis building, data analysis and discussions to refine the coding (authenticity) over a two year time period.

Participants. Research participants included 247 rural 4th and 5th grade students. These children were enrolled in one of two engineering education programs [either *Engineering is Elementary* (EiE) or our own, developing program, *Engineering is Everywhere* (E²), for this study we were interested in a broad collection of children's drawings of engineers so we could make sense of the varying displays of children's conceptual understanding. Of the potential drawings (247 students x 2 pre/post-tests x 3 image frames), we analyzed a total of 940 images (due to the number of blank frames on the pre-tests).

Analysis. Data were analyzed by eight researchers through a constant comparison of data. Emerging categories and theoretical sampling of children's illustrations and notes helped to maximize determination of the similarities and differences among student responses and along the rubric continuum.^{23,24} We easily established four continua of interest: gender stereotypes, usefulness of science, usefulness of mathematics, and understanding of the work of an engineer. Challenging decisions included definition of the levels along each continuum and the differing experience and viewpoints of the research team (scientists, mathematicians, educators, and an engineer). Over time, researchers progressed through four rubric iterations before settling on the current version. Earlier versions of the rubric attempted to micro-measure children's levels of knowledge and understanding on a 6 stage continuum. Finally, the children's work came to define and confirm this working version and a 3-4 stage continuum. Our process involved repeated propositions and search for evidence in the mDAET work samples we had collected. We realized children left clues about their thinking in each frame overall -- so the rubric must be applied holistically. That is to say, any information in the frame (i.e. speech balloon, response to any prompt) might be used as scoring evidence on any continuum. In this process we learned to include verbatim examples in the scoring rubric to manage for objectivity and limit interpretation. This process of distillation finally allowed reliable scoring decisions across the research team.

Results

The resulting theoretical propositions were organized into a rubric that follows on the work of Farland-Smith's¹⁹ expanded assessment of children's drawings of scientists. Rubric guidelines provide decisive descriptions and examples of actual student responses to guide scoring decisions. Generally, 0 is the low score (vague, superficial understanding) and 2 is the highest score (detailed, explicit understanding).

Engineer's use of mathematics. Across this continuum, children might receive a score of 0-2. Low end responses include instances where the child does not reference a mathematics application or indicates mathematics is not used; mid-range responses identify mathematics an engineer might use (such as *adding* or *measuring*); and high-end responses identify a mathematical application within the context of an engineer's work (such as *see how much oil to mix*). Figure 1 illustrates the qualitative difference between the mid-range and advanced conception levels.

Engineer's use of science. Similarly, this feature is measured along a similar continuum and scores might range from 0-2. Low end responses include instances where the child does not reference a science application or indicates science is not used; mid-range responses identify a science skill or concept an engineer might use (such as *electricity* or *experimenting*); and high-end responses identify a scientific application within the context of an engineer's work (such as *testing which design works best*). Figure 2 illustrates the qualitative difference between the mid-range and advanced conception levels.

Gender stereotype of an engineer. The gender stereotype feature, where the stereotypical assumption is that all engineers are male, is measured along a continuum that ranges from 0-3. Children are asked to identify whether or not the engineer in each drawing is a male or a female. With responses at the low end of the continuum, no stereotype can be determined (i.e. no information or conflicting information). Along the mid-range of the continuum, the child might either indicate the engineer is male or the engineer is female. At the highest level of the continuum, the child indicates that gender does not matter (i.e. *could be a boy or a girl*) or indicates engineers a group of individuals working as a team. Figure 3 illustrates the qualitative difference between the mid-range and expanded conception levels.

Work of an Engineer Continuum. The work of an engineer is measured along a continuum that ranges from 0-3 and defines a range of understanding about the kind of work an engineer might do (the what) and the motivation of an engineer to improve things or solve a problem (the why). With responses at the low end of the continuum, vague activities or mistaken ideas are presented (i.e. *driving a train*). At the next level, a child identifies stereotypical notions about the work of an engineer (i.e. *repair cars, build houses*). At mid-range levels of this continuum, the child identifies a specific field of engineering (i.e. *mechanical engineering*) or suggests engineers are designers (i.e. *phones* but does not reference a problem or need). At the highest level of the continuum, the child indicates engineers create or design things to solve a problem (i.e. *improve gas mileage*). Figure 4 illustrates the qualitative difference between the low and mid-range conception levels.

Limitations

There are several limitations to the current study. Child participants were limited to rural, Oklahoma students. Results are limited to 4th and 5th grade data only. Though we collected 2nd and 3rd grade student data, we learned that the majority of students at this developmental level were not able to add the necessary level of detail in the narrative explanations. Though the mDAET rubric is dependent on a convenient sample situated in Oklahoma, we expect these results will appeal universally with those seeking to maximize elementary engineering education

programs. Lastly, we recognize that not all engineering programs are identical, though mDAET does align well with the principles expected by the NRC.²

Conclusions, Implications, and Future Research

We set out to expand the DAST and DAET procedures to capture a continuum of children's understanding about the work of engineers. We hoped to identify the varied range of children's conceptual understanding about the work of an engineer – most especially how children understand engineering as applied science and mathematics. Our grounded theory methods gave rise to a rubric continuum that organizes children's thoughts and ideas into a valuable, contextual measure of children's understanding of engineering. Broadly applicable to elementary engineering education contexts, the developed rubric measures children's understanding as it relates to applied science and mathematics in design and problem-solving efforts to improve the quality of human lives. This sensitive tool can help engineering educators determine the range of children's knowledge and understanding of the work of an engineer on a continuum from limited to advanced conception levels. We expect this rubric might be used as a formative or summative tool – to provide feedback on children's progression or to evaluate engineering education curricula.

Implications. Given our theoretical frame of expectancy value (where persistence and academic achievement are influenced by the child's *expectancy for success* and *subjective task value*), we are especially pleased with the way this rubric captures children's understanding about how engineers apply science and mathematics. First, these details can help to substantiate the time and expense of implementing an engineering education program. One might argue engineering applications can give purpose and meaning (*subjective task value*) to science and mathematics learning as well as test-alternatives that demonstrate children's ability and potential (*expectancy for success*). These two features of engineering education can help to encourage engineering as a career option.

We expect the mDAET measure will prove useful as a formative program assessment as it provides greater access to children's conceptual understanding of an engineer's place in society than current surveys allow. Certainly, a pre-test would help teachers recognize children's initial misconceptions and tailor instruction to challenge new thinking and understanding. Additionally, we expect teachers might recognize the importance of explicit teaching strategies aligned with the Committee on K-12 Engineering Education guiding principles.² As Capobianco et al.¹⁰ suggested, naïve student ideas can help advance curriculum design.

Future Research

Future research will necessarily need to establish validity and inter-rater reliability of this scoring rubric. Having begun to explore inter-rater reliability, we plan to create a scoring guide to insure objectivity of rubric scorers. This guide will present examples of children's illustrations and a rationale for thinking about continuum score assignment. Our exploration with mDAET coding procedures thus far suggests such a guide will help to maintain inter-rate reliability (i.e. help coders refrain from interpreting or assuming children's meaning).

Other potential research initiatives might analyze a collection of children's naïve conceptions of the work of an engineer and organize these child stories into professional development

workshops for engineering education teachers. This research might follow on the work of Driver at al.²⁶ who studied students' conceptions and their implications for planning curricula and designing instruction. Certainly, elementary classroom teachers themselves may hold some of these same conceptions. As Yoon et al.²⁷ learned, teachers need to find a level of comfort in subjects that they do not know well.

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Figure 1. Engineer's Use of Mathematics

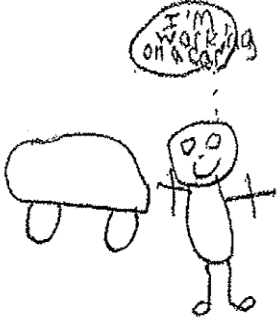

A. Basic Conception	B. Advanced Conception
 <hr/> <ol style="list-style-type: none"> 1. Is this person a male or female? male 2. How is the engineer using math? He is working with gages and stuff 3. How is the engineer using science? He has to work with gas 4. A sentence about the engineer's work: He is working on the metal. 	 <hr/> <ol style="list-style-type: none"> 1. Is this person a male or female? Male 2. How is the engineer using math? Estimateing how many gallons of water to put in the concrete 3. How is the engineer using science? concrete 4. A sentence about the engineer's work: He is making concrete
<p><i>Figure 1.</i> In example A. Basic Conception, the child presents an engineer who is “working with gages [sic] and stuff.” This reference to mathematics is appropriate, but the application is vague, not well explained. In example B. Advanced Conception, the child explains the engineer is using math by “estimating how many gallons of water to put in the concrete.” In this example, the child identifies a reasonable application of mathematics and provides a reason why an engineer would apply mathematics (i.e. math with a purpose).</p>	

Figure 2. Engineer's Use of Science

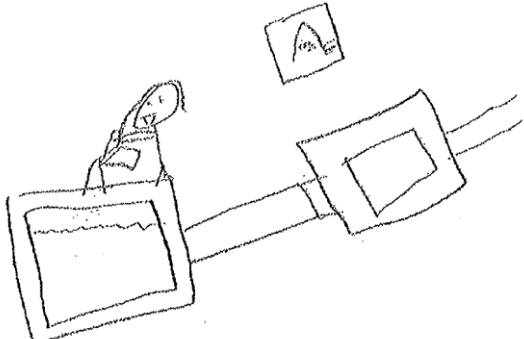
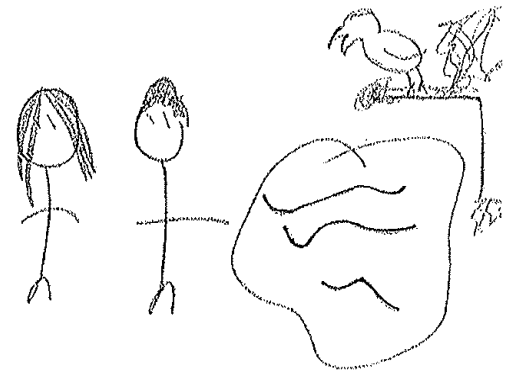
A. Basic Conception	B. Advanced Conception
 <hr/> <p>1. How is the engineer using math? finding out the cost.</p> <p>2. How is the engineer using science? Testing chemicals.</p> <p>3. A sentence about the engineer's work: She is making a water filter.</p> <p>4. Is the engineer a girl or a boy? girl</p>	 <hr/> <p>1. How is the engineer using math? How many animals live there</p> <p>2. How is the engineer using science? whats there hapitat and were they live.</p> <p>3. A sentence about the engineer's work: The engineers are improving the enviorment</p> <p>4. Is the engineer a girl or a boy? girl</p>

Figure 2. In example A. Basic Conception, the child presents an engineer who is “testing chemicals.” While this is a science process an engineer might use, we are not able to determine how the chemical testing applies to the water filter design. In example B. Advanced Conception, the child indicates the engineer will need to explore the animals’ current habitat (“whats there [sic] habitat” in order to improve their environment. In this example, the child provides a reasonable application of science and provides a reason why an engineer would apply science (i.e. science with a purpose).

Figure 3. Gender Stereotype of an Engineer


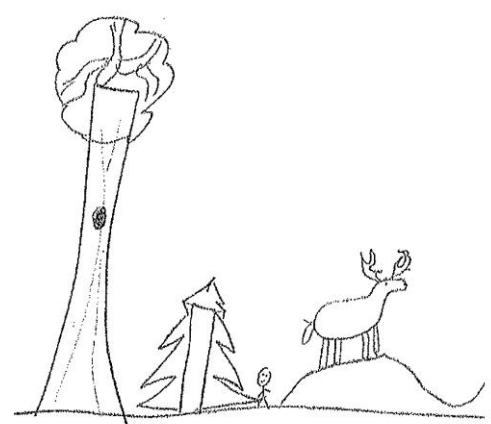

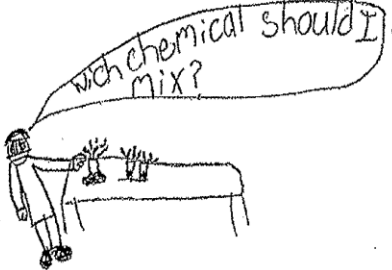
A. Traditional Conception	B. Expanded Conception
 <p>1. How is the engineer using math? dot know</p> <p>2. How is the engineer using science? ever theying <i>they know</i></p> <p>3. A sentence about the engineer's work: don know</p> <p>4. Is the engineer a girl or a boy? <i>boy</i></p>	 <p>1. How is the engineer using math? <i>by giving information</i></p> <p>2. How is the engineer using science? <i>by studying the animal.</i></p> <p>3. A sentence about the engineer's work: <i>studying the in vier ment</i></p> <p>4. Is the engineer a girl or a boy <i>ether one</i></p>
<p><i>Figure 3.</i> In example A. Traditional Conception, the child indicates this engineer is a “boy.” In example B. Expanded Conception, the child indicates the engineer could either be a boy or a girl. This advanced thinking indicates expanded thinking – beyond the traditional “engineering is for boys” or the non-traditional “engineering is for girls.” Illustrations that identified a group of engineers working as a team were scored similarly.</p>	

Figure 4. Work of an Engineer

A. Naïve Conception	B. Basic Conception
 <p>1. Is this person a male or female? <u>female</u></p> <p>2. How is the engineer using math? <u>Not sure</u></p> <p>3. How is the engineer using science? <u>Not sure</u></p> <p>4. A sentence about the engineer's work: <u>she is fixing a phone</u></p>	 <p>1. Is this person a male or female? <u>male</u></p> <p>2. How is the engineer using math?</p> <p>3. How is the engineer using science? <u>He is using science while he is working with chemicals.</u></p> <p>4. A sentence about the engineer's work: <u>He is trying to make a new water proof liquid.</u></p>
<p><i>Figure 4.</i> In example A. Naïve Conception, the engineer is shown “fixing a phone.” This child holds the mistaken idea that engineers are “fixers.” In example B. Basic Conception, the child indicates the engineer is “trying to make a new waterproof liquid.” In this example, the child identifies work an engineer might do (the what) and suggests engineers create or design things. Additional details about how this new product solves a problem (why we need it) would place this illustration at the next level, Advanced Conception. Interestingly, our data mirrored Cunningham, et al.’s (2005) data where the majority of children associated fixing and building with engineers and few students understood design as a central feature of engineering.</p>	