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The Development of a Systematic Coding System for Elementary Students' Drawings of Engineers

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ABSTRACT

The Draw an Engineer Test (DAET) is a common measure of students' perceptions of engineers. The coding systems currently used for K-12 research are general rubrics or checklists to capture the images presented in the drawing, which leave out some of the richness of students' perceptions, currently only captured with an accompanying student interview. The purpose of this study is to build a reliable coding system, which first establishes an inventory of pictorial elements irrespective of their potential relationship with engineering and second captures aspects of students' engineering perceptions inductively (from the ground up) while at the same time incorporating categories from previous research. The coding system will be used to help researchers understand how young students' perceptions of engineering, engineers, and the work of engineers evolve and are impacted by interventions. The longterm goal of this project is to create a standalone measure that can be broadly applied to diverse populations, and to create a large multi-institution student database, with both K-12 and university populations represented. This database would provide a rich dataset for better understanding common misconceptions about engineering and thus enabling the development of methods to address them.

Key Words: engineering, children, drawings, social constructivism, assessment

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With the integration of engineering into the elementary classroom (NAE, 2009) and an increase of research in early and pre-engineering, the engineering education research community is faced with the same question as the science education community: How can we adequately explore young children's understanding of engineering? Punch (2002, p. 322–323) describes in her comparison of methods of research how children differ in the following assumptions: (a) children are different from adults and as such should be researched with ethnographic methods; (b) children are similar to adults with different competencies; (c) children are different from adults merely in regards to ethical considerations such as consent and confidentiality. This article is situated between assumption (a) and (b), stating that research with children, particularly young children, is different from research with adults (James, Jenks, &Prout, 1998) due primarily to the differing competencies of expression (Nesbitt, 2000). Acknowledging the differences in expression between children and adults, our research is focused on improving what Punch calls "methods which are based on children's skills" (2002, p. 322). One of the most described skills of children is drawing (Nesbitt, 2000) and the combination of a drawing and writing approach is becoming critically appraised and increasingly popular as a technique to capture children's thoughts (Backett-Milburn & McKie, 1999; France, Bendelow, & Williams, 2000; Pridmore & Bendelow, 1995). Our context to research children's understanding of engineering is a revised schema for the existing "Draw an Engineer Test" (Knight & Cunningham, 2004).

Theoretical Framework

Following our assumptions, while most research approaches with children are described and tested as solely methods and/or techniques, our approach is theoretically grounded as well. Here we examined the process of young children's drawings through a social constructivist theoretical framework, a Vygotskian (Vygotsky, 1962) lens. In a social constructivist context, experiences are shared to construct meaning, where the knowledge is co-constructed by the combination of prior and new knowledge (Brooks, 2004). A learner constructs meaning and understanding through the surrounding socio-cultural environment (Vygotsky, 1978). Vygotsky theorized a connection between thought and speech and the development of verbal thought, and the forms to communicate this might include symbols, algebraic systems, art, writing, diagrams and language (Brooks, 2004, 2009; Vygotsky, 1962). The significance of children's drawings is described by Brooks (2004) who states that "when we consider children's drawing to be a form of communication and a meaning-making tool, then the social, the cultural and the historical relationship with this meaning-making process demands careful consideration" (p. 1). Therefore, when we use children's drawings, we are not merely utilizing an artistic form of expression, but a unique language. This lens allows us to utilize children's drawings as speech-acts (Bretherton & Beeghly, 1982), which express what a child understands about engineering and engineers. The task to code and analyze children's drawings analogically then becomes a translation task similar to translating from another language.

Literature Review

Researchers have been studying children's drawings for decades in an attempt to put words to the marks of crayons, markers, pens, and pencils left on paper by children when asked to draw a particular object (Kosslyn, Heldmeyer, & Locklear, 1977). "Piaget argued that a child's drawing performance reflected the child's cognitive competence. He did not consider drawing to be a special domain of development but merely a window into the child's general cognitive development (Brook, 2009, p. 1; Piaget & Inhelder, 1967)."

Children's drawings have been used in a variety of settings as a means of assessment and as a method of gathering information in a non-threatening way. Children's drawings have been used as an effective pre/post assessment (Bowker, 2007; Weber, 2008) and to see differences in children's perceptions (Barraza, 1999; Bowker; Weber). Drawings have also been used to assess attitudes and misconceptions about scientists and engineers (Chambers, 1983; Knight & Cunningham, 2004). These studies demonstrate the basis for our study.

Understanding students' perceptions of engineers and the work they do is important, as these perceptions can influence students' understanding and beliefs about the profession, and their consideration of pursuing the profession as a career (Knight & Cunningham, 2004). Assessing attitudes and knowledge about engineering and engineers

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has often been observed through the Draw an Engineer Test (DAET; Knight & Cunningham, 2004), which grew out of the Draw a Scientist Test (DAST; Chambers 1983). In the DAET, children are asked to draw a picture of an engineer and then asked a series of questions about engineering. Pioneering this assessment tool, Knight and Cunningham (2004) administered the DAET to 384 students in grades 3–12 and found that most young students believed that engineers "build buildings and fix car engines" (p. 7).

Taking this a step further, Cunningham, Lachapelle, and Lindgren-Streicher (2005) used the results of the DAET to create a 16-image survey called "What is an Engineer?," where students are asked to circle the pictures where engineering is represented and then answer the question, "An engineer is a person who ______." The second part of this assessment is a 16-image survey called "What is Technology?," where students are asked to circle the pictures where technology is represented and then answer the question, "How do you know if something is technology?" Cunningham and her fellow researchers at the Museum of Science, Boston, continued their research, moving towards a more quantitative method of assessing students' understanding of engineering (Lachapelle, Cunningham, Oware, & Battu, 2008). Research using the DAET reappeared in 2008, when Oware conducted a study using the drawing assessment with an accompanying individual interview to examine elementary students' perceptions of engineers, and as a result used the two vantage points of data to create a detailed coding rubric (Oware, 2008). Fralick, Kearn, Thompson, and Lyons (2008) then developed a checklist for cataloguing items in a DAET drawing for a middle school student population.

Researchers at The Institute for P-12 Engineering Research and Learning (INSPIRE) were interested in building on the previous research by developing a detailed coding system of children's drawings that could be used reliably without the need for additional data such as student interviews. Coding systems that are currently in use rely on interview data to provide a complete representation of student perceptions, which can be time consuming and expensive. This coding system was developed to provide a rich description and inventory of pictorial elements in students' drawings first, without evaluating their relationship to engineering and secondly to score the drawing in order to gain a more complete understanding of students' perceptions of engineers and engineering, and subsequently incorporating many of the components included in previous rubrics (Oware, 2008) and checklists (Fralick et al, 2008). This study describes the process of developing the detailed coding system that can be used reliably as a stand-alone measure of students' perceptions of engineering, building on previous research.

Research Rurpose

The purpose of this study was to develop a rich coding system that could be used to reliably assess elementary students' responses to the DAET. This coding system would then be used to evaluate an educational intervention aimed at integrating engineering into an elementary curriculum. The primary goal of this intervention was to increase engineering literacy in young students. The coding system will also be used to help researchers understand how young students' perceptions of engineering, engineers, and the work of engineers evolve and are impacted by interventions. The long-term goal of this project is to create a stand-alone measure of the DAET drawing that can be broadly applied to diverse populations, to create a large multi-institution student database, with both K-12 and university populations represented, to better understand common misconceptions and develop methods to address them.

Methodological Considerations

DAET Administration Components

The participants in the DAET were the 2nd through 4th grade students whose teachers had received an INSPIRE engineering intervention. The intervention was a week-long summer engineering academy where the elementary teachers learned ways to integrate engineering into their existing curriculum. Because it was important to represent students' understanding of engineering as knowledge was constructed, teachers administered the DAET as a pre-post assessment, both before and after engineering instruction. Student participants represented ethnically diverse populations from both urban and suburban elementary schools, including 10 participating classrooms from one school district in the south central United States.

The teachers first attended an engineering academy, facilitated by INSPIRE in their home school district. During the academy, the teachers participated in several engineering activities covering topics such as engineering design, mathematical modeling, engineering professions, scientific inquiry as a basis for engineering, and technology as a product of engineering. When the teachers returned to their classrooms in the fall, they agreed to teach the engineering lessons/curriculum they had learned in the academy, and they agreed to administer the DAET both before any engineering instruction took place (pre) and after all engineering instruction had taken place (post).

In the administration of the DAET assessment, each student participant received the DAET form and a writing utensil of their choice (e.g., color crayons, pencils, or markers). Students were told, "*In the box on your piece of paper, draw an engineer doing engineering work.*" They were then allowed to draw freely for 20 minutes. They also answered the writing prompt, "What is the engineer doing?" Both the drawing and the written answers to the question were analyzed in the creation of the DAET coding system.

Each student drawing was assigned an identification number (sample shown in Figure 1). Identification items such as gender, ethnicity, and/or grade were removed prior

Figure 1. Student DAET Drawing, with example identification number.

Table 1
Specific Sample Size per Iteration

Iteration			Total Drawings
Iteration One			180
Iteration Two	*Pre*		93 (*Pre 42*, *Post 51*)
Post			
2nd Grade	14	17	31
3rd Grade	15	18	33
4th Grade	13	16	29
Iteration Three			79 (*Pre 37*, *Post 42*)
2nd Grade	12	19	31
3rd Grade	14	8	22
4th Grade	11	15	26
Iteration Four			84 (*Pre 41*, *Post 43*)
2nd Grade	10	19	29
3rd Grade	16	8	24
4th Grade	15	16	31
Iteration Five	*Changes were made to the existing coding system through literature review and team discussions; no student drawings were analyzed*		
Iteration Six			20
Coding System Verification			20

to coding in an effort to reduce coder bias, forcing coders to judge drawings based only on the content provided by the students and not on any identifying student information. Additionally, the identification number prevented the coder from knowing if the drawing being evaluated was a pre or a post drawing, thus further reducing bias.

Interrater Reliability

The coding system needed to have an acceptable interrater reliability (i.e., 80% using liberal measurements) before it could be used to assess the student drawings. A more conservative measure of interrater reliability takes into account all sources of unreliability, including chance agreements (e.g., Krippendorff's α, Scott's π), while a liberal measure simply calculates the percentage of agreement or correlation between raters (e.g., Pearson's reliability coefficient, agreement coefficients; Krippendorff, 2009). While more liberal criteria (e.g., .70 agreement coefficient) are typically used for indices that are more conservative or for exploratory research (Lombard, Snyder-Duch, & Campanella Bracken, 2002), Neuendorf's (2002) review of typical cutoffs for interrater reliability found that .90 is an acceptable criteria for all types of situations, and that .80 or greater is acceptable for most situations.

Results

Coding System Development

The INSPIRE DAET Coding System was developed using a grounded theory approach (Corbin & Strauss, 1990), using the students' drawings, written answers, and interview transcripts in initial iterations, with open coding used to develop initial categories. A total of 476 drawings were used to develop the coding system. A breakdown of the number of drawings used in each iteration of development is shown in Table 1. During the initial code development, all occurrences of objects and ideas represented in the students' DAET were recorded so as to not miss anything in the children's drawings. Axial coding was then used to condense and refine the codes. As the coders looked for patterns among the codes recorded during open coding, the codes were collapsed into categories of like ideas or codes. Later, the ideas were merged and given variable labels with specific code instructions (see Appendix A.1). Throughout the coding system development, we continued to follow a grounded theory approach (Corbin & Strauss, 1990) and incorporated previous essential research (Fralick et al., 2008; Knight & Cunningham, 2004; Oware, 2008; Prabha & Garg, 2000; Weber, 2008). Throughout several iterations of the coding system, codes were refined, collapsed, added, and discarded based on their presence in drawings, students' written answers, researcher discussions, and prior research findings.

The INSPIRE DAET Coding System emerged from the students' drawings and written descriptions via six coding iterations. Following the final round of coding, the coding system had seven major classifications: *Humans*, *Human-Engineered Objects*, *System*, *Environment*, *Vibe*, *Engineering Field Portrayed*, and *Engineering Understanding* (see

Table 2
Classification Descriptions

Code and Description Text Hierarchy: Classification—*Category*—"Subcategory"—Focal Areas	Initial Introduction
1. *Humans*: The student draws an engineer as a human (defined as either a female/male/ or ambiguous). Or, the student draws the engineer as a non-human (defined as an object).	Iteration 1
2. *Human-Engineered Objects*: The student draws objects used by, created by or thought to be created by engineers such as vehicles, machines, tools, structures, and/or engineering artifacts.	Iteration 1 2–as split category 3–stand-along category 5–name change
3. *System*: The student indicates a process (*such as the engineering design process*), or that the engineering in the drawing is taking place for a purpose or benefit. Additionally, the student lists verbs (correct or incorrect) associated with engineering.	Iteration 1
4. *Environment*: The student indicates where the drawing is taking place (natural elements, human-managed elements, and detail of location).	Iteration 2
5. *Vibe or Affect*: The student's drawing is determined to have a positive/neutral/negative atmosphere based on the items contained within the drawing and the written description of the drawing.	Iteration 2 5–name change
6. *Engineering Field Portrayed*: The student's drawing portrays an engineering field (e.g. mechanical, electrical). The student adds details to the engineer represented, such as clothing or objects, and may indicate attitudes/dispositions associated with engineers/engineering. The student's drawing is judged on the ability to match the engineering profession to the engineer drawn.	Iteration 5
7. *Engineering Understanding*: The student's understanding of engineering is judged to be plain if the student has 0–3 engineering details drawn (i.e. clothing, objects, attitudes, match between engineer/profession, occurrences in the field), and detailed if the student has more than 3 engineering details drawn.	Iteration 1 5–name change

Table 2). What follows is a description of the evolution of the coding system. The evolution of the coding system is diagrammed in Appendix A.2.

Coding Iteration One

The first iteration, of 180 drawings, resulted in four major classifications: Humans, Objects, System, and Engineering. Under each of the major classifications there were categories, and then subcategories. Humans had two categories: *Engineer as Person*, and *Other Human Beings*. Objects had four categories: *Natural Objects, Human-Made Objects, Tools,* and *Engineering Artifacts*. System had three categories: *Process Present, Activities of Engineer,* and *Intention of Engineering*. Engineering had one category: *How Sophisticated*. Within this iteration, data were collected through a description, evidence (picture, text, both, interview), and certainty (Likert Scale 1–5) for each category. Coders would be asked to provide a description of the category being observed (e.g., if the coder saw natural objects in the picture s/he would note a description of those natural objects). The coder would then be asked to indicate how s/he knew that the category was present in the picture (e.g., Did the child draw the natural object, write about the natural object, both draw it and write about it, or speak about it in an interview?). Finally, the coder would be asked to indicate, via a Likert scale (1–5) how certain s/he was that that category was actually present in the picture (e.g., How certain are you that the natural object is what you think it is?). For the *Engineer as a Person* category of the Humans classification, the description section was pre-set as "male, female, or multiple" meaning that the student drew a male human, a female human, or multiple humans.

Coding Iteration Two

After reviewing 93 student drawings we identified three main areas for refining the coding system. First, within the Humans classification, we noticed that some students referred to themselves as the engineer, so a new category *Student as Engineer* was added. Students also drew a non-human engineer (e.g., a car engine), so we needed to add the *Engineer as Non-Human* category to the Humans classification as well. As we considered the engineer to be depicted as a human initially, the new realization that a student could consider the engineer as a non-human was important to monitor, and here it was important to keep both concepts connected, thus keeping within the same initial Human classification. The overall classification may be changed in the future, once a better fit is determined.

Second, within the Objects classification, we also felt that the *Human-Made Objects* category was too broad and needed to be broken into two independent subcategories: "Intention of Engineering" and "Engineering." The former included four focal areas: "Vehicles," "Machines," "Tools," and "Structures." Items in these subcategories would be coded if a student intended for an item to be engineering, but leaned more towards another profession (e.g., mechanic). Within the *Human-Made Objects* category, the "Engineering" subcategory had the same focal areas (Vehicles, Machines, Tools, Structures) plus an additional area of Engineering Artifacts. Items in these subcategories would be coded if a student drew an object that represented engineering. We separated the subcategories of "Vehicles," "Machines," "Tools," and "Structures" because of the intention behind the students' drawings. If a student drew a picture where one of these subcategories was represented, we evaluated the drawing to determine if the student had drawn a picture intended to be engineering, or if s/he had drawn a picture that was truly representative of engineering. For example, if a student drew a car, s/he would receive a "Vehicle" code. If the car was represented by an engineer fixing the car, the "Vehicle" code would be coded under the "Intention of Engineering" subcategory. However, if the student drew an engineer designing a car, the "Vehicle" code would be coded under the "Engineering" subcategory. Since "Intention of Engineering" was moved into the *Human-Made Objects category*, it was removed from the System classification.

Third, new stand-alone classifications were necessary to capture more detail in two areas: Environment (the place where the drawing is taking place) and Affect/Disposition (e.g., smiling in the picture, worried faces). In addition, five new categories were created within the Engineering classification: *Engineers as Other Professions* (e.g., when students represent engineers as professions other than engineering, such as firemen or teachers), *Engineering as Science* (engineering and science are the same thing), *Who Benefits from Engineering, Clothing* (level of detail), and *Problems Associated with Engineering* (negative aspects of the career). Last, since the purpose of this coding system is to be used on drawings alone, we were at the point that the interview data could be removed, and eliminated "interview" as an evidence option.

Iteration Three

For the third iteration, we reviewed 79 student drawings. Here within the Humans classification, we noticed that we were unable to describe some of the humans represented as either male or female, so we added an "ambiguous" coding subcategory to the *Engineer as a Person* category. Also within the Object classification, differentiating between the two *Human-Made Objects* categories was also difficult, so we consolidated the two categories back into one, and gave the category six subcategories: "Vehicles," "Machines," "Tools (Physical Labor)," "Tools (Office)," "Structures," and "Engineering Artifacts."

Iteration Four

In the fourth iteration, we reviewed 84 student drawings. In the Humans classification, some students shaded their drawings, so we added a "shaded/not shaded" subcategory. Secondly, some students included stick figure drawings of humans, while others contained a more detailed representation, so the subcategory "stick/partially developed/developed" was added to describe the human(s) drawn, to specify where the energy is spent in the drawing. Lastly, some students were assigning a proper name to their engineers (e.g., Tom, Jamie); to capture this we added a *Name the Engineer* category.

There were additional areas of clarification, first within the System classification, where we added the *Intention of Engineering* category to indicate why the engineering was taking place. Second, in the Engineering classification, we removed both the *Engineering as Science* and *Problems Associated with Engineering* as they were difficult to capture reliably. More broadly, we modified the Affect/Disposition classification to be just Affect (e.g., smiling in pictures, worried faces), and we added the category of *Attitudes/Dispositions* to the Engineering classification in an effort to capture students' perceptions of the feelings of and towards engineering (e.g., "I love engineering!"). Additionally, we started noticing that some students were mentioning specific engineering disciplines and the work associated with those engineering disciplines, which prompted us to add the classification of Engineering Fields and the category of *Work Associated with that Engineer* replacing the original category of *Engineers as Other Professions*.

Iteration Five

At this time, we brought a new team member on board, who completed a doctoral dissertation in children's drawings and coding systems. After team discussions, we made three initial changes to help align our current coding system with the coding system implemented in her dissertation. First, we added Vibe to the classification of Affect, along with the following three categories: *Negative, Positive,* and *Neutral*. The second change was within the Environment classification, where there were three overall categories; *Environment (where), Natural,* and *Human-Managed*. The first referred to where the drawing was taking place, first discussed in iteration two. The new categories *Natural* and *Human-Managed* (referred to as Man-Made in Prabha & Garg, 2000 and Human-Managed in Weber, 2008) were added to achieve a deeper description of the drawing and to align the coding system with previous work in the area of environmental awareness. *Human Managed* contained five subcategories: "Religion," "Social", "Education," "Political," and "Science and Technology." The *Natural* category catalogued the many aspects of nature captured in the children's drawings. The six subcategories of the *Natural* category were: "Hydrosphere," "Lithosphere," "Atmosphere," "Plant," "Animal," and "Humans." Third, to determine how detailed the students' drawings were, we added the category of *Detail* (also from the above dissertation work: Weber, 2008), with two subcategories: Plain (0–3 variables included) and Detailed (more than 3 variables included). Changes were as noted in the existing coding system as well, within the Humans, Objects, System, and Engineering classifications. In addition, both a codebook and scoring sheet were developed in an effort to streamline the coding process, with variable code names and coding instructions assigned for each of the subcategories.

Within the Humans classification, "stick or developed figure" category was removed. The Objects classification included six corresponding categories: *Vehicle, Machine, Physical Labor Tools, Office Tools, Engineered Structures,* and *Engineering Artifacts*. *Engineered Structures* was a category that underwent some revision to encompass structures that are final products of civil engineering design. Additionally, *Engineering Artifacts* was a category that also underwent revision to include objects associated with the planning stages of engineering design. The System classification contained seven categories with reformatted definitions: *Process* (a process is represented)*, Engineering Verbs* (writes verbs that are associated with engineering, even if that conception of engineering is not a correct conception)*, Why* (provides an explanation for why the engineering is taking place)*, Benefit* (people or organizations portrayed that will benefit from the engineering happening in the drawing), and the written description representation counterpart for each. *Who Benefits* was then removed from the Engineering classification.

Last, the Engineering Field Portrayed classification had 6 categories: *Engineering Field, Match, Clothing, Objects, Attitudes/Dispositions,* and *Attitude provided (written)*. The category of *Engineering Field* included codes for specific engineering disciplines, as did the categories of *Clothing* and *Objects* that were both adapted from previous research (Fralick et al., 2008; Knight & Cunningham, 2004; for more detail please see Appendix A.1) For the category of *Match*, the student received a number based on their ability to match the work of the engineer with the explicit discipline they described. We also replaced the *How sophisticated* category with *Engineering Concept* category, because making the judgment on the level of engineering "sophistication" in a student's drawing (scale of 1–5) was proving to be difficult when attempting to gain agreement among coders. The new category included three levels: no understanding, some understanding, and understands.

Iteration Six

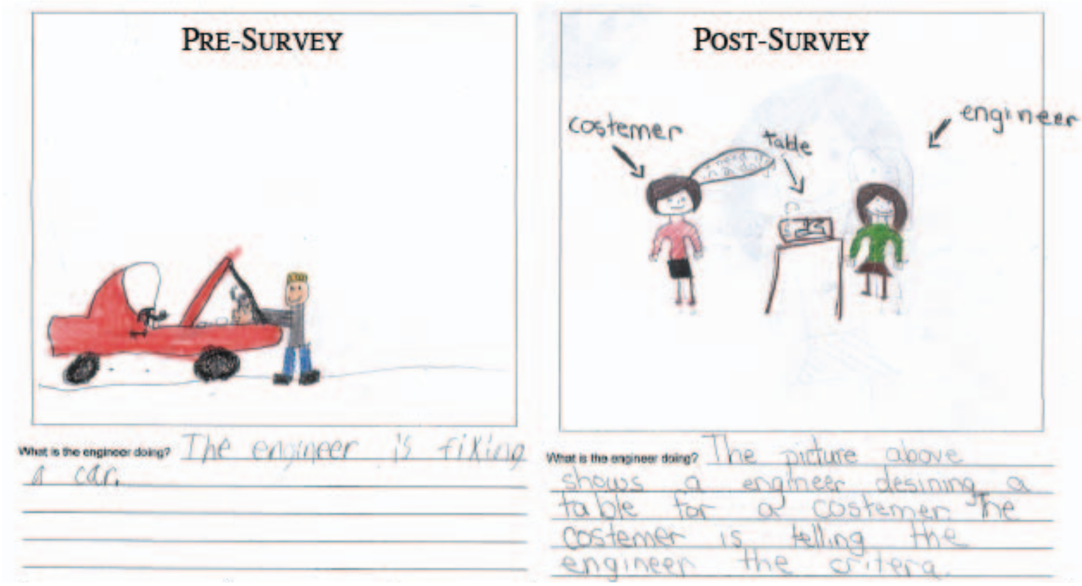
For the sixth and most recent iteration of the INSPIRE DAET Coding System, we retained most of the properties of the fifth iteration with only minor changes. Under the Humans classification, the subcategory of "Gender" was included on the initial coding systems; however, it was inadvertently left off of Iteration five and as a result re-included on the sixth iteration. Name changes included a modification within the same classification, the *Other Humans* category was renamed *Group*, where a number system was not required. The Object classification was changed to Human-Engineered Objects, due to the *Natural Objects* category being moved to the Environment classification. Also, within the Environment Classification, the two subcategories of the *Environment* category were each renamed "Location" to ease coding. Finally, a new *Detail in the Engineer* category was added to the Engineering Field Portrayed classification, where the level of detail in the engineer would be determined by adding the number of occurrences in the field, clothing, object, and attitude subcategories, removing the "stick or developed figure" as a subcategory in the Human classification. As previously, a drawing with 0–3 occurrences is considered plain, while a drawing with 4 or more occurrences is considered a detailed drawing of an engineer. We removed the *Match* category, as it was too difficult to determine.

Coding System Verification

Initial verification of the coding system took place after the sixth iteration, where two researchers independently coded 20 drawings (see example in Figure 2). For example, the pre- drawing is coded 1 for a human, 1 for a shaded face, 2 for the male gender, and 1 for a vehicle present in the drawing. Zeros were given for the other categories in the drawing because there was no evidence for their presence (e.g., the setting was not in an office). In contrast, the post drawing is coded for the presence of a human, a shaded face, the male gender, an office setting(person is seated at a table), and artifacts (blueprint/drawing). We elected to use critical incident sampling (Patton, 2002), choosing 20 of the most difficult cases to code. The drawings were a mixture of both pre and post drawings, and a balance of 2nd through 4th grade students' work. The coders were unaware of the grade level of the student and of the pre/post status of the drawing as they coded the drawings. After the critical incident drawings, the initial interrater reliability was calculated to be 81.7%. Minor changes were made to the DAET coding system, specifically in the *System, Engineering Field Portrayed*, and *Engineering Understanding* categories.

The DAET coding system was then refined through a series of sessions where two coders (including one new coder) independently scored a set of 10 DAET student responses and then met to discuss areas of disagreement, for two rounds while continuing to refine the coding system by discussing areas of disagreement. The interrater reliability was calculated to be 80.1% for the first round and 82.8% for the second round (Table 3). Then for the last round, we scored 10 DAET student-drawing responses with 4 coders, resulting in an average interrater reliability of 79.5% and an overall reliability between the four coders at 79.9%.

In an overall comparison, each rater was compared against the codes of the entire group, allowing for trouble spots to become more visible (Table 3). Having four coders review (or analyze) the same data can shed light on what is really going on with the rubric; however, this level of information could potentially be lost if not compared across the group. Traditionally, each data point is considered an agreement or disagreement between two coders independently from the group, without seeing where real issues lay or where there may be simple mistakes by someone not fully understanding the concept or even rushing through the data (see Table 3: Personal Disagreements/Researcher 2). The overall average is calculated by looking at each data point across the coders and seeing how each coder has rated



Humans	human	1
	student	0
	name	0
	face	1
	gender	2
	group	0
Human-Engineered Objects	vehicle	1
	machine	0
	physical	1
	office	0
	structure	0
	artifacts	0

Humans	human	1
	student	0
	name	0
	face	0
	gender	1
	group	1
Human-Engineered Objects	vehicle	0
	machine	0
	physical	0
	office	1
	structure	0
	artifacts	1

Figure 2. Application of Coding System

that component compared to the others. In this overall comparison average, three values were used, including: a) full agreement (0), b) full disagreement (1), and c) minimal disagreement (.25). For the full agreement, all coders had the same score for that data point. For a full disagreement, there was a fifty percent (two or more) disagreement on the score provided. When one person was different from the group, a minimal disagreement was counted, which is a percent based on the total number of coders (4). Table 4 shows an example of how the overall reliability was calculated based on the coders' level of agreement.

Table 3
Interrater reliability

Round (Coders/Drawings)		Inconsistent Scores	Total Scores	Percent Agreement
Round 1: (2/ 10)	Coder 1 vs. Coder 2	83	361	80%
Round 2: (2/ 10)	Coder 1 vs. Coder 2	75	437	83%
Round 3: (4/ 10)	Coder 1 vs. Coder 2	87	405	79%
	Coder 1 vs. Coder 3	83	407	80%
	Coder 1 vs. Coder 4	77	395	79%
Traditional Average				80%
Round 3: (4/ 10)	Overall Comparison Average	81.75	406.75	80%

Interpretation, Discussion and Future Steps

With the lens of social constructivism, we utilized children's drawings as a means to elicit information about their perceptions about engineers and engineering. To assess these perceptions, the purpose of this study was to develop a coding system to score students' drawings of engineers. The major strength of the INSPIRE DAET Coding System is that it provides a detailed account of students' drawings of engineers and engineering. This detailed account will allow researchers to investigate students' perceptions of engineering, engineers, and the work that engineers do. Additionally, this coding system, once validated, will serve as a stand-alone measure of students' perceptions of engineers

Table 4
Overall Reliability Example

Coder	Survey ID:	Human or Non-Human	Gender	Structure as Final Product	Process Represented
1	39	Person	Female	No Mention	No Mention
2	39	Person	Female	No Mention	Mentioned
3	39	Person	Ambiguous	Mentioned	Mentioned
4	39	Person	Female	No Mention	No Mention
1	22	Person	Ambiguous	No Mention	No Mention
2	22	Person	Female	No Mention	Mentioned
3	22	Person	Ambiguous	No Mention	No Mention
4	22	Person	Female	No Mention	No Mention
1	6	Person	Female	Mentioned	No Mention
2	6	Person	Female	Mentioned	Mentioned
3	6	Person	Female	Mentioned	No Mention
4	6	Person	Female	No Mention	No Mention
1	11	Person	Ambiguous	No Mention	No Mention
2	11	Person	Female	No Mention	Mentioned
3	11	Person	Ambiguous	No Mention	No Mention
4	11	Person	Ambiguous	No Mention	No Mention
1	42	Person	Female	No Mention	No Mention
2	42	Person	Male	Mentioned	Mentioned
3	42	Person	Ambiguous	Mentioned	No Mention
4	42	Person	Ambiguous	No Mention	No Mention
Total Number	20	5	5	5	5
Disagreements	6	0	2.5	1.5	2
			[(.25 ×2) +2]	[(.25 ×2) +1]	[(.25 ×4) +1]

Personal Disagreements

Coder	Total				
1	0	0	0	0	0
2	5	0	1	0	*misunderstanding of concept* 4
3	2	0	1	1	0
4	1	0	0	1	0

for the DAET assessment, thus eliminating the necessity for an accompanying student interview.

As with any coding or cataloguing system, some of the richness present when an interview accompanies the drawing may be lost. Additionally, there may be times when items in the drawing are interpreted incorrectly by the coder. These weaknesses of the coding system are mitigated, however, by the fact that a coding system allows a much greater number of drawings to be analyzed than would be possible if interviews were required to interpret the drawings.

The next phase is to validate the coding system as a stand-alone measure of student perceptions of engineers and engineering by triangulating a student DAET coding results with his or her interview. To do this, INSPIRE researchers will be integrating supplemental questions targeted at different components of the drawings in the standard DAET post-interview protocol. These questions will be used during the interview to verify that the coder reliably sees the same components the student describes that s/he drew in the picture, to ensure that the student's perception of the drawing and the researcher's perception of the drawing align. To do this, the researchers will compare drawings *(coded without the aid of an interview)* to student interview responses *(independent of the coder looking at the actual drawing)*.

This research is part of a larger project aimed at assessing students' understanding of engineering, and this tool can be used as a pre/post inventory around an engineering intervention to show where students are in their conceptions and understanding of engineering. Researchers can then use results from the DAET to modify and improve professional development, curriculum, and instruction to better meet the needs of students, and ensure that students develop more informed perceptions of engineers and engineering. The development of a coding system for the DAET will enable researchers to assess children's general understanding of engineering and how these perceptions change as a result of exposure to engineering.

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Appendix A.1. DAET Codebook

Where Found?	Definitions	SPSS Variable Name	Coding Instructions
Survey #	Survey ID	***survey#***	***number assigned***
HUMANS: *People in Drawing*	**Human:** the engineer represented in the drawing is a person *(not an object).*	**human**	**0 -**No mention **1 -** Person **2 -** Non-Human **99 -** Blank
	Non-Human: the engineer represented in the drawing is an object *(not a person).*		
	Student as Engineer: a student makes reference to him or herself as being the engineer.	**student**	**0** -No mention **1** -Mentioned **99**-Blank
	Name: the student gives a proper name to the engineer *(e.g. James, Lydia)*	**name**	
	Face: Face of the engineer is shaded in	**face**	**0**- Not Shaded **1**- Shaded **99**- Blank
	Gender: human engineer was depicted as a male, female, or ambiguous *(drawn and/or written)*	**gender**	**0**-No Mention **1-** Female **2-** Male **3 -Ambiguous** **99-** Blank
	Group: other human beings are represented in the drawing *(other than just the engineer)*	**group**	**0**-No mention **1**-Mentioned **99**-Blank
Human-Engineered Objects	**Vehicle:** any type of vehicle *(e.g. car, plane)*	**vehicle**	**0**-No mention **1**-Mentioned **2-** Unclearly drawn item **99**-Blank
	Machine: the drawing depicts any type of machine *(large or small /found in any setting and **not** a vehicle).*	**machine**	
	Tools (physical labor): the engineer using tools associated with physical labor *(hammer, drill)*	**physical**	
	Tools (office): the engineer using tools associated with office work *(pencil, easel)*	**office**	
	Structures: depicts a structure that is a final product of a civil engineering design *(house, building, bridge)*	**structure**	
	Artifacts: depicts objects associated with the planning stages of engineering design *(blueprints, drawings)*	**artifacts**	
SYSTEM *what, why, who*	**Process:** a step-by-step process represented, including at least 2 clearly defined linear steps *(the engineering design process, the scientific process)*	**process**	
	Engineering Verbs: writes verbs that are associated with engineering, even if that conception of engineering is not a correct conception *(e.g. fix cars, design bridges)*	**verbs**	*write in…*
	Engineering verbs provided…. write in	**verb2**	
	Why: provides an explanation for why the engineering is taking place *(intention with product design and/or criteria: to keep water away from the house, so it will work)*	**why**	*write in…*
	Explanation provided…. write in	**why2**	
	Benefit: people or organizations portrayed that will benefit from the engineering happening in the drawing *(a car owner will benefit from a car being fixed).*	**benefit**	**0**- No mention 1- People/ Family 2- Community 2- Organizations 3- Other **99**-Blank
	Benefit: If the student explicitly writes who will benefit from the engineering (*explicit*), or if the student implies who will benefit from the engineering (*implicit*).	**benefit2**	**0**-No mention **1**-Explicit **2**- Implicit **99**-Blank

Appendix A.1. *Continued*

ENVIRONMENT	**Location:** Sometimes it is explicit *(written)* and sometimes it is implicit *(implied).*	**Location2**	**0**-No mention **1**-Explicit **2**- Implicit **99**-Blank
	Location: where the drawing is taking place *(you know that the scene is taking place in a garage because the engineer is fixing a car, outside, in an office, etc.)*	**location**	**0**-No mention **1**-Mentioned **99**-Blank
HUMAN MANAGED	**Religion**: Church, cross, Christmas tree, temple	**religion**	
	Social: House, group of children, parents, market, games, pool	**social**	
	Political: Flag, leader	**political**	
	Education: school, book, teacher, black board, desk, environmental message	**education**	
	Science and Technology: bus, car, TV, computer, hospital, traffic light, gun, chimney, bike	**science**	
NATURAL *Abiotic*	**Hydrosphere:** rain, river, fountain, well, stream	**hydro**	
	Lithosphere: mountain, hill, rocks, land, soil, peak	**litho**	
	Atmosphere: clouds, moon, sun, stars, sky, black smoke, gases	**atmo**	
Biotic	**Plant:** Tree, garden, flower, park, lawn, fruit	**plant**	
	Animal: cow, dog, duck, animal skull, birds	**animal**	
	Humans: human beings, human skull *(including the engineer when represented as human)*	**human2**	
DETAIL	***Human Managed (5)+ Natural (5) = #*** **Plain:** *less* than 3 variables included in drawing (**0-3** variables) **Detailed:** *more* than 3 variables included in drawing (**4+** variables)	**detail**	**0-** Plain **1-** Detailed **99**-Blank
VIBE *or Affect*	**Feeling of Drawing OVERALL:** **Negative:** sad face, "keep out" sign **Positive:** happy face, "welcome" sign, environmental message **Neutral:** cannot tell	**vibe**	0- Negative ☹ 1- Positive ☺ 2- Neutral 😐 **99**-Blank
ENGINEERING FIELD PORTRAYED	**Field:** any explicit engineering fields that the student mentions in the drawing or in the corresponding sentences.	**field**	**See page 3…**
	Clothing: explores the clothing worn by the engineers (*e.g. glasses, lab coat*, *see following page*)	**clothing**	**See page 3…**
	Objects: explores the objects with the engineers (*e.g. computer, robot, see following page*)	**object**	**See page 3…**
	Attitudes/ Dispositions: explores the attitudes of the **engineer(s) ONLY**. Does the student mention the engineers feeling a certain way? *(e.g. famous, mad, happy, nervous, nice*)	**attitude**	**0**-No mention **1-** Explicit 2- Implicit **99**-Blank
	Attitude provided: explores feelings/attitudes ***of engineers*** (famous, mad, happy, nervous, nice, ☺)	**attitude2**	*write in*
	Detail in the Engineer: ***field + clothing (#)+ object (#) + attitude*= #** *Plain = 0-3, Detailed =4+ (same as above in "detail")*	**detaile**	**0-** Plain **1-** Detailed **99**-Blank
ENGINEERING?	This category explores whether or not the student has a grasp on the concept of engineering. Does the student understand what engineering is? ***Indicator Components:*** *teamwork, design process, broader applications (like teaching)* ***NO UNDERSTANDING:*** *Student presents no understanding of the concept of engineering?* ***SOME:*** *Is their conception of engineering still forming (1 component + some misperceptions present)?* ***UNDERSTANDS:*** *Does the student have a well-formed conception of engineering (1+ component)*	**concept**	**0**-No mention **1-no** understanding 2-**some** understanding 3-**understands** **99**-Blank

WORK (ENGINEERING FIELDS):

0- No Mention
1- Aeronautics and Astronautics
2- Agricultural and Biological
3- Civil
4- Chemical
5- Computer
6- Construction
7- Electrical
8- Environmental
9- Industrial
10- Land Surveying and Geomatics
11- Materials
12- Mechanical
13- Educational
14- Policy
99- Blank

CLOTHING *(adapted from Fralick, Kearn, and Thompson 2009)*:

0- No Mention
1- Lab Coat (Lab suit)
2- Crazy Hair (*Einstein*)
3- Goggles/ Glasses
4- Laborer's Clothing (*overalls, hard hat*)
5- Business Attire (*skirt/pants*)
6- Casual (*pants/shirt*)
7- Other details (*hat, gloves, detailed hair*)
99- Blank

OBJECTS *(adapted from Fralick, Kearn, and Thompson 2009):*

0- No Mention

1- Building/Fixing Tool
2- Measuring Tool
3- Writing Tool

4- Studied Animal
5- Other Animal
6- Studied Plant
7- Other Plant
8- Rock

9- Robot
10- Computer

11- Passing Vehicle
12- Constant Vehicle
13- Flying Vehicle
14- Rocket
15- Train/truck

16- Other machine *(technology)*
17- Furniture (*chair, table, easel*)
18- Civil Structure (*mechanic shop/garage, factory, fence*)

19- Book
20- Signs of thinking (*thinking bubble*)
21- Signs of teaching (*classroom, blackboard*)
22- Signs of action (arrows)
23- Blueprint/ Drawing
24- Model
25- Diploma

26- Math *(symbol, etc.)*
27- Chemistry *(symbol, etc.)*
28- Medicine *(symbol, etc.)*
29- Meteorology
30- Sports

31- "Danger" *(Keep out Sign, weapon)*

32- Other

NOTES:

Erased= NOT in drawing

Appendix A.2. Coding System Progression

Classifications	Iterations: 1	2	3	4	5	6	
Humans *People in Drawing*	*Engineer as Person* *Other human beings*	*Engineer as Non-Human* *Student as engineer*	(a) Gender (ambiguous)	(b) Face shaded (c) Stick/ partial/ developed figure *Name the Engineer (Tom, Jamie)*		(a) Gender (re-added) ~~(c) Stick/ developed figure~~ *Group*	**Human** **Gender** **Face** **Student** **Name** **Group**
Objects	*Natural Objects* *Human-made Objects* *Tools* *Engineering Artifacts*	(a) Intention of engineering (b) Engineering - vehicles - machines - tools - structures - engineering artifacts	*Intention of engineering* vehicles, machines tools (physical labor), tools (office), Structures Engineering Artifacts	~~*Intention of engineering*~~	~~Natural Objects~~ *Vehicles* *Machines* *Physical Labor Tools* *Office tools* *Engineered structures* *Engineering artifacts*	**Human-Engineered Objects**	**Vehicle** **Machine** **Physical** **Office** **Structure** **Artifacts**
System *what, why, who*	*Process Present* *Activities of Engineer* *Intention of Engineering*	~~Intention of Engineering~~		*Intention of Engineering (Why)*	*Process* *Engineering Verbs* *Why* *Benefit (Who)*		**Process** **Verbs** **Why** **Benefit**
		Environment *(location where taking place)*			*Environment* *Human-managed* *Natural (abiotic/biotic)* *Detail (location)*	Location	**Location** **Human-Managed** *w/sub-categories* **Natural** *w/sub-categories*
Engineering	*How sophisticated*	**Affect/ Disposition** *(smiling in picture, worried faces)* *Clothing* *Who Benefits (from engineering)* *Engineers as Other Professions (firemen)* *Engineering as Science* *Problems Associated with Engineering*		*Affect/* ~~*Disposition*~~ **Engineering Field Portrayed** Work Associated with Engineer *Disposition/ Attitude* ~~*Engineers as Other Professions*~~ ~~*Engineering as Science*~~ ~~*Problems Associated w/ Engineering*~~	*Vibe/ Affect* *Engineering Field* *Match* *Clothing* *Objects* *Attitudes/Dispositions* ~~*Who Benefits*~~ *Match* ~~*How sophisticated*~~ *Concept*	*Detail (engineer)* ~~*Match*~~	**Detail** **Vibe** **Field** **Clothing** **Object** **Attitude** **Detail e** **Concept**