ELECTRONIC JOURNAL FOR RESEARCH
IN SCIENCE & MATHEMATICS EDUCATION
VOL. 27, NO. 1, 30-57

Elementary Students' Representations of Scientists and Engineers: Disciplinary Conflations and Confusions Before and After a Semester with an Engineer

Jacob Pleasants
University of Oklahoma

Iliana De La Cruz
Texas A&M University

Joanne K. Olson
Texas A&M University

ABSTRACT

Current U.S. science education reform efforts call for engineering to be included as part of science instruction at all grade levels. As students experience engineering instruction alongside science, an important question is how students conceptualize the nature of those two fields, and especially the extent to which they differentiate science and engineering. In this study, grades 3-5 students in thirteen classrooms participated in engineering activities as part of their science instruction for a 16-week semester. During that semester, students also interacted with an engineering graduate student who regularly visited the classroom to plan and implement science and engineering activities. Before and after that semester, we analyzed students' responses on the Draw-A-Scientist Test and the Draw-An-Engineer Test. Unlike prior analyses of those instruments, our approach focused on the alignment of students' drawings with the activities and processes of professionals in those two fields. At the time of the pretest, students' representations of scientists and engineers were often misaligned with the targeted fields, and overall alignment improved modestly from pretest to posttest. An important question was whether students would conflate the fields of science and engineering, especially after experiencing engineering as part of their science instruction. Although some evidence of conflation exists, we did not find an increased prevalence of conflated drawings from pretest to posttest. The results indicate that the inclusion of engineering activities in the science classroom does not necessarily lead students to confuse science with engineering, but also that significant work needs to be done to help students accurately conceptualize the nature of work in those fields.

Keywords: nature of science; nature of engineering; elementary education; engineering education; draw a scientist; draw an engineer

Introduction

An enduring goal for K–12 science education efforts has been to help students better understand the nature of science, which includes an understanding of what science is, how scientific knowledge is developed, and how scientists do their work (Clough, 2006; Lederman & Lederman, 2014; McComas & Clough, 2020). Unfortunately, many students have misconceptions about science and scientists, likely developed from exposure to inaccurate portrayals found in science instruction, curriculum materials, and the media (Clough, 2006; Finson, 2002; Schibeci, 1986). For decades, a common method of probing young students' conceptions of scientists has been the "Draw-A-Scientist Test" (DAST), which is an open-ended instrument in which students draw a scientist engaged in scientific work. The task was originally developed by Chambers (1983) and has been modified multiple times, often by changing the prompt or adding additional written items to the task (e.g., Christidou et al., 2016; Farland-Smith, 2012; Losh et al., 2008). A long line of research has indicated a consistent stereotypical view of scientists. With minor variations, the "standard" image of a scientist produced by young students is a white male, robed in a lab coat, engaged in mysterious laboratory work with bubbling chemicals (Barman, 1999; Chambers, 1983; Christidou et al., 2016; Flick, 1990; Finson, 2002; Kelly, 2018; Mead & Metraux, 1957; Schibeci, 1986).

A complexity that has been introduced by current science education reforms, such as the Next Generation Science Standards in the United States (NGSS; NGSS Lead States, 2013), is that engineering is expected to be taught alongside science (Moore et al., 2015; National Research Council [NRC], 2012). As engineering has become more common in K–12 classrooms, interest has grown in K–12 students' conceptions of engineering (e.g., Capobianco et al., 2011; Lachapelle & Cunningham, 2014; National Academy of Engineering [NAE] & National Research Council [NRC], 2008). To investigate students' conceptions of engineering, Knight and Cunningham (2004) modified the DAST to develop the "Draw-An-Engineer-Test" (DAET), which prompts students to "Draw an engineer doing engineering work" and also provides space for respondents to explain what the engineer is doing. Studies using the DAET have found that students tend to erroneously represent engineers engaging in manual labor tasks rather than the more "mental" process of technological design and development (Capobianco et al., 2011; Chou & Chen, 2017; Fralick et al., 2009; Knight & Cunningham, 2004; Rynearson, 2016; Weber et al., 2011). Although misunderstandings have been documented using the DAET, researchers have not yet found a "standard" stereotypical image for engineers like that found for scientists (Capobianco et al., 2011).

The erroneous conceptions revealed by students' representations of scientists and engineers are concerning for multiple reasons. Cultivating student interest in science and engineering is a common educational objective, but such efforts are undermined when students misunderstand the nature of those disciplines (American Society for Engineering Education [ASEE], 2020; Finson, 2002; Montfort et al., 2013; NAE & NRC, 2008, 2009; Reinisch et al., 2017). Students who, for instance, think of science mostly as a solitary activity of mixing chemicals in a laboratory might wrongly conclude that science is of little interest to them (Luo et al., 2021). Similar issues would likely arise for students who associate engineering mostly with car repair (ASEE, 2020; Capobianco et al., 2011; Fralick et al. 2009). A broader concern is that because engineering is now often being taught in the science classroom, students might not develop accurate distinctions between the two fields, despite their substantial differences. McComas and Nouri (2016) argue that the way in which engineering is treated within the NGSS, as well as recent efforts to promote STEM integration (e.g., Kelley & Knowles, 2016; Roehrig et al., 2021), is part of the problem:

> Science and engineering are quite distinct disciplines both philosophically and practically. Therefore, we should be much more focus directed to help all those involved with science teaching understand the important engineering/science distinction. With this in mind, it is problematic that the Nature of Science distinction between science and engineering appears only twice in the NGSS. Also, many have suggested that blending science and engineering, and even adding the other two parts of STEM in the elementary grades, is a good idea. However, we see no note of concern in the NGSS that learners – particularly those in the early grades – understand the separate roles of science and engineering (McComas & Nouri, 2016, p. 571).

Why exactly *should* students differentiate science and engineering, given their clear relationship? Of course, pointing out the differences between science and engineering is not a denial of the connections and similarities between the fields. The reason to highlight distinctions, as well as connections, is that both are vital to the longstanding efforts to promote scientific and technological literacy. An essential part of those literacies is an understanding of the roles that scientists and engineers play in society (ASEE, 2020; International Technology and Engineering Education Association [ITEEA], 2020; NGSS Lead States, 2013). To imply that there is no difference between the roles of scientists and engineers is contrary to a foundational educational goal. Put another way, ignoring or eliding the differences between science and engineering misrepresents both the nature of science and the nature of engineering – both of which are valued parts of STEM education (McComas & Burgin, 2020; NAE & NRC, 2009; NRC, 2012; Pleasants & Olson, 2019a).

Prior studies indicate that targeted interventions can reduce students' stereotypical images of scientists, particularly those that provide students with more accurate exemplars of scientists and scientific inquiry (Christidou et al., 2016; Finson et al., 1995; Flick, 1990; Huber & Burton, 1995; Sharkawy, 2012). Similarly, interventions that provide students with authentic engineering experiences and more accurate examples of engineers can reduce certain erroneous images on the DAET (Lachapelle & Cunningham, 2007; Rynearson, 2016). However, few studies have compared students' representations of both scientists and engineers, and none have explored how science instruction that incorporates engineering affects students' representations of both fields. In general, investigations of how students differentiate science and engineering are lacking, which is problematic given the concerns raised about disciplinary confusions (McComas & Burgin, 2020; McComas & Nouri, 2016; Zeidler et al., 2016).

In one of the few studies to examine students' views about science and engineering, Karatas et al. (2011) used interviews as well as a drawing task to investigate sixth-grade students' understanding of the nature of engineering. The interviews they conducted with students included a question probing students' thinking about the difference between engineering and science. They found that many of the students confused science and engineering. Although some articulated differences between the fields, many did so by indicating that scientists and engineers are both researchers, but that they research different things: scientists study natural things, whereas engineers study machines. A study by Fralick et al. (2009) also provides some insight into how students think differently about scientists and engineers. They gave the DAET and DAST to a large group of middle school students and compared students' representations across the two instruments. The main difference they found between students' representations was that scientists were more often shown indoors working in a laboratory, whereas engineers were shown outdoors doing manual labor. A limitation of their study was that the DAET and DAST were completed by different groups of students. A further limitation of both studies is that neither examined how students' views *changed* as a result of instruction.

Missing from the literature are comparisons of how the same group of students represent scientific and engineering work, the extent to which those representations accurately reflect the differences between those fields, and the ways in which those representations change after instruction. The goal of the present study is to address those gaps in the literature. In this study, grades 3–5 students' drawings of scientists and engineers were examined before and after a 16-week semester during which they received science instruction that included multiple engineering experiences, as advocated by the NGSS. The study was conducted within the context of a professional development project in which participating teachers were teamed with engineering graduate students who supported the integration of engineering content and activities into science instruction. The students in the study therefore not only experienced science and engineering instruction, but also interacted with an engineering expert.

In this study, we examine changes that occurred in students' conceptions of scientists and engineers over the course of the project, focusing on the extent to which students' representations of scientists and engineers accurately reflect each field. In the following section, we describe the framework that we used to conceptualize the distinctions between science, engineering, and technology, which we then used as a basis to analyze students' representations. Our study seeks to address the following research questions:

1) How do grade 3-5 students' representations of scientists and engineers align with scientific, engineering, and technological activity both before and after receiving science and engineering instruction?
2) To what extent do grade 3-5 students' representations demonstrate conflation between the work of scientists and engineers before and after receiving instruction?

Conceptual Framework: Differentiating Science, Engineering and Technology

Because our study seeks to examine the extent to which students' representations of scientists and engineers accurately represent work in those fields, clarity is needed regarding the distinguishing characteristics of those fields. This task also requires that attention be paid to the field of technology, given the many intersections and interactions that exist between technology, engineering, and science. Much can be said about the interactions and similarities between science, engineering, and technology, but our primary goal in this section is to focus on *distinctions,* given the research questions we seek to address. The approach we take to drawing distinctions is to focus on the divergent goals and purposes of science, engineering, and technology (McComas & Burgin, 2020; Pleasants, 2020; Vincenti, 1990).

Technology occupies an unusual status in that it is less a field or discipline than it is a set of products, systems, and processes (Dusek, 2006; Mitcham, 1994). Taking an approach common in the philosophy of technology (e.g., Kroes, 2012; Mitcham & Schatzberg, 2009), we adopt a broad definition of technology that includes all human creations that are oriented toward practical purposes. In terms of goals and purposes, therefore, technological activity includes all human activity oriented toward the creation and maintenance of human-made products and systems. The field of engineering is similarly concerned with the design and development of technological systems (Kroes, 2012; Mitcham, 1994). The field of engineering is therefore a subset of the broader array of technological activities. Many technological activities, of course, are not engineering; engineers focus on design and development of technological systems rather than the actual work of production, repair, or maintenance (Bucciarelli, 1994; Dym & Brown, 2012; Kroes, 2012; Mitcham, 1994). A car mechanic, therefore, is engaged in technological activity, but not engineering. To enable further design and development, engineers also engage in "engineering science," research work that produces knowledge about technological systems (Bucciarelli, 2009; Houkes, 2009; Mitcham & Schatzberg, 2009). Although many technologies are designed and developed by engineers, engineering is not the sole source of novel technologies; invention is not synonymous with engineering (Newberry, 2013). A craftsperson who creates a novel piece of furniture or a tinkerer who creates a new tool might be said to have engaged in invention, but not engineering.

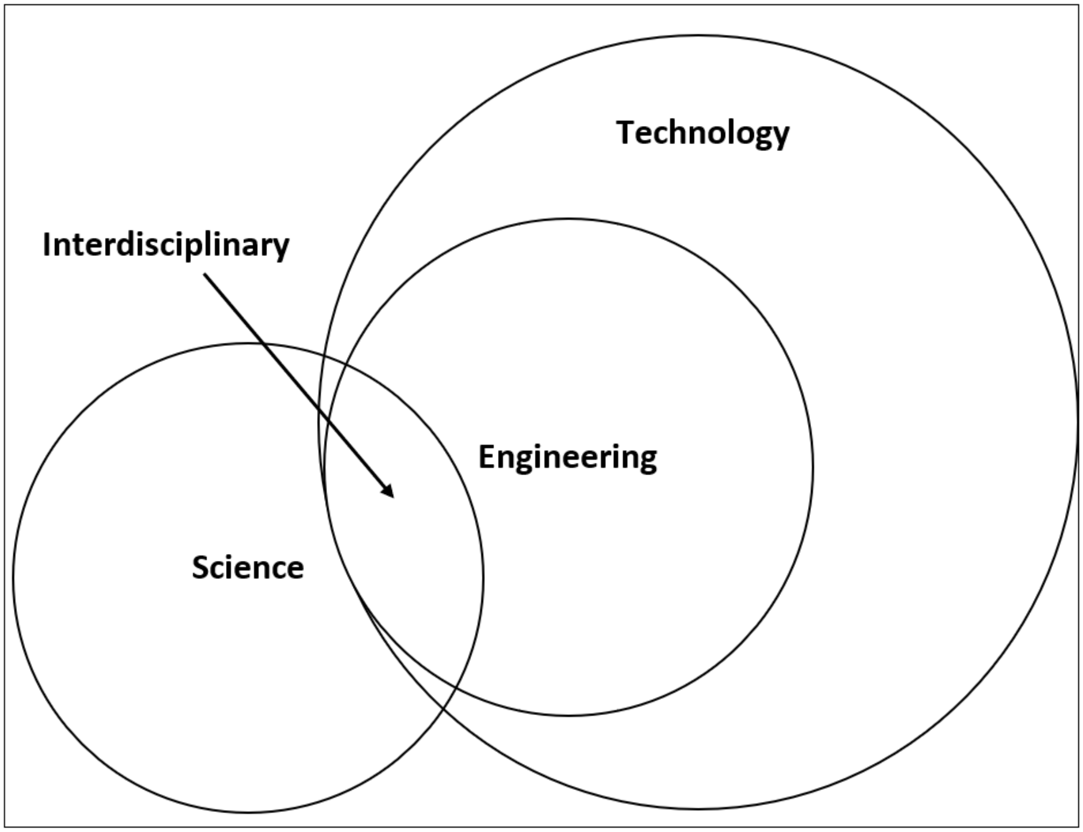
In contrast to engineering and technology, the goal of science is primarily to produce knowledge of the natural world. In conducting their work, scientists of course make extensive use of technological equipment and thus frequently repair, refine, and develop their instruments in order to advance their research into the natural world (Ihde, 2009; Pitt, 1995). Scientists might also create things that did not exist before, as when a chemist synthesizes a novel substance in a laboratory. Yet even when scientists engage in technological activities, their work differs from that of an engineer or technologist in that for the scientist, the goal is to produce scientific knowledge rather than a novel technology (Vincenti, 1990). Galileo and Newton both made considerable contributions to the development of the telescope, but for both scientists the telescope was foremost an instrument of scientific knowledge production (Pitt, 1995). Similarly, when a chemist produces a chemical in the laboratory, they do so in order to advance chemical knowledge. When a chemical engineer produces a new chemical, they do so for practical reasons; perhaps the chemical has properties that are useful for the industry in which they work, and is therefore highly marketable, provided it can be produced cheaply enough.

The distinctions drawn above are necessarily simplifications of what is, in reality, a more complex state of affairs. Scientists are not blind to practical considerations, and much scientific research is done with potential applications in mind. Scientific and technological goals can also be simultaneously pursued within the same project (Vincenti, 1990; Volti, 2005), as illustrated by "big" projects such as the development of the atomic bomb (Hoddeson et al., 1993). Even if disciplinary borders are blurry, rather than sharply defined, important differences nevertheless exist between science, engineering, and technology (Pigliucci, 2013; Pleasants & Olson, 2019b; Vincenti, 1990). While not a philosophically perfect method of demarcation, a focus on the divergent goals of the fields is conceptually useful, particularly from an educational perspective (McComas & Burgin, 2020; Pleasants, 2020). Understanding the goals of science and engineering allows learners to better comprehend the different, though at times overlapping, roles played by each within society – an important component of scientific and technological literacy (ASEE, 2020; ITEEA, 2020; NRC, 2012). Differentiating the fields based on their goals is also likely to be more comprehensible to students than focusing on more subtle epistemological or methodological distinctions.

Our conceptual framework is summarized in Figure 1. Engineering is shown as a subset of technological activity. Science is shown as distinct from engineering/technology while also allowing for an overlapping interdisciplinary space.

Figure 1

Conceptual Relationships Between Science, Engineering and Technology



Applying the Framework to Student Representations

We developed the conceptual framework described above to ground our approach to analyzing students' drawings and support the construct validity of our methods (Schreier, 2012). As described in the following section, we used it as a starting point to categorize students' representations of scientists and engineers and determine the extent to which their representations were accurately aligned with those fields. Because our research questions also seek to identify instances of conflation, within our framework, we operationally define "conflation" as an instance where a representation portrays scientific work as engineering or vice-versa. For example, a portrayal of a scientist engaged in technological design or development in pursuit of practical goals, rather than for the goal of knowledge production, would qualify as an instance of conflation.

In developing our conceptual framework, we necessarily attended to many nuances and complexities that inevitably arise when trying to draw distinctions between fields that are as interconnected as science, engineering, and technology. Attention to complexity is crucial when establishing conceptual categories from a research perspective. However, we do not imply that *students* ought to understand the disciplinary landscape at that level of detail, particularly at the elementary level. Indeed, there is not yet consensus regarding the depth to which students at varying age levels ought to understand multiple aspects of the nature of science, engineering, and technology (Abd-El-Khalick, 2014; ITEEA, 2020; Pleasants & Olson, 2019a). Our conceptual framework, therefore, is not necessarily a prescription for what students *ought to learn*. Rather, it is a tool to make sense of what students' views *currently are*.

Methods

This study took a sequential mixed methods approach in which qualitative data (students' drawings of scientists and engineers) were transformed into numerical data for quantitative analysis

(Teddlie & Tashakkori, 2009; Fetters et al., 2013). The transformation process took place via a qualitative content analysis (Schreier, 2012). This methodology allowed us analyze a large data set of student drawings and identify patterns and differences between pretests and posttests as well as between the DAST and DAET.

Context of the Study

The study took place as part of a broader teacher education and professional development research project aimed at supporting the incorporation of engineering into elementary science instruction. Student teachers and their cooperating teachers, all in grades 3–5 classrooms, participated in the project and each pair was teamed with an engineering graduate student (called "engineer" hereafter) to form a triad for a 16-week semester. The engineers spent one full day per week in the classroom with their triads to help plan and implement science and engineering lessons. The triads completed a 2-day professional development workshop before the semester, a 1-day workshop midway through the semester, and were also provided ongoing support from project staff. Additionally, the engineers also participated in an on-campus course that met weekly to support their work in schools, provide ongoing instruction in pedagogy, and help them navigate their roles as content experts within their triads.

The primary objective given to participants was to modify their science curricula to better support students' learning of science concepts while also incorporating engineering experiences into instruction. The project workshops modeled inquiry-based science and engineering design activities, with emphasis on the ways that engineering can be meaningfully connected to science in the classroom. The project gave participants access to *Engineering is Elementary* curriculum materials developed by the Boston Museum of Science (2007), and the school district provided teachers with *Full Option Science System* (FOSS) curriculum (Lawrence Hall of Science, 2015). Teachers were not required to use the provided curricula; rather, they were given discretion to modify and develop materials suited to their individual contexts.

The project provided participating teachers with several experiences to help them better understand the relationship and difference between science and engineering as well as accurately communicate the disciplines to their students. The pre-semester workshop included a 30-minute presentation by an engineering faculty member on the nature of the engineering discipline and the ways that scientific knowledge is used in engineering. It also included a 60-minute session during which a science educator addressed the nature of science and ways that science and engineering are connected, yet different. After participants experienced the modeled science and engineering lessons, the facilitators also raised the issue with participants that students might conflate the two disciplines and encouraged participants to address that issue with their students. Given their expertise, the engineers were called upon to communicate the characteristics of engineering to help students see the ways in which it is similar to, yet different from, science.

Triads were not required to incorporate specific engineering activities into their classrooms or follow a prescribed approach to instruction. Because triads were situated in different grades and different schools, the specific science content they addressed and the learning activities that they implemented varied. Nevertheless, there was a relatively consistent pattern of implementation that occurred across the triads in terms of how they implemented engineering activities and how the engineers engaged with the students.

Triads' science instruction typically followed the FOSS curriculum aligned to their grade-level science standards. During science instruction, the engineers assisted the teachers in modifying the FOSS activities to be more engaging for students, and also often co-taught those activities. During science, the engineers were therefore positioned primarily as "science co-teachers" or "science experts" in the classroom rather than "engineering experts." The triads typically incorporated engineering into their science instruction by placing an engineering design challenge at the end of one of their FOSS units. The engineers took substantial roles in terms of conceptualizing and planning those activities, linking them to the science units being taught, and implementing the activities with students. All triads implemented at least one engineering design challenge with their students, and most implemented between two and four over the course of the semester. With few exceptions, the design challenges followed a common structure: students were tasked with designing a technology to solve a problem, given a set of criteria and constraints, then worked in teams to generate ideas, test those ideas, and improve them.

Observations of triads' instruction indicated that explicit conversations about the nature of engineering (or the nature of science) were rare during engineering design challenges (Pleasants, 2018; Pleasants & Olson, 2021). The only substantial amount of time that triads typically devoted to explicitly addressing the nature of engineering occurred when the engineers initially introduced themselves to their students. During their first visits to their classrooms, the engineers typically delivered a presentation on their field of engineering, what engineers in their field do, and what projects they were working on. Those presentations often included some discussion of how the engineers used scientific knowledge to do their own work, but rarely overtly addressed how their work differed from science.

Instruments

The instruments used in the present study were versions of the DAST (Chambers, 1983) and the DAET (Knight & Cunningham, 2004). Because we sought to compare responses on the two instruments, we used forms of the DAST and DAET that were as similar as possible. In our version of the DAST, respondents were tasked with drawing "a scientist doing science," and below the drawing area, space was provided to explain in words what the scientist was doing. The DAET was identical to the DAST, except that it asked the respondent to "Draw an engineer doing engineering work." Like the DAST, the DAET provided the respondent with space below the drawing to explain what the engineer was doing. The exact forms of the DAST and DAET used in this study are provided in the appendix.

Participants and Data Collection

Triad members administered the DAST and DAET to their students at the beginning and end of their semester of participation in the project. Electronic copies of the DAST and DAET were made available to the triad members, along with instructions for their administration, and those who chose to use them did so as part of their normal classroom instruction. Although the authors were not present during administration, triad members indicated that they gave the DAST and DAET in a manner consistent with the guidelines of the instrument developers (Knight & Cunningham, 2004), taking about 10 to 15 minutes to do so (no time limits were imposed by the triads). In several cases, we received data from triads who modified the instruments or did not follow the guidelines for their administration; data from those triads were not included in the study. Both the DAST and DAET were administered as pretest and posttest; pretests occurred before or on the day of the engineer's first visit to the classroom, and posttests on or after the day of the engineer's final visit. Triads sent copies of completed responses to the researchers after de-identifying them by replacing student names with ID numbers so that students' pretest and posttest responses could be matched.

We obtained complete data sets from 13 different triads located in 10 different schools, all within the same large, diverse urban school district located in the Midwestern United States. Demographic information about the students, triad members, and schools are provided in Table 1. In total, 280 students completed one or more drawings, but some student responses were missing, either because they did not complete a drawing or produced a drawing that was too unclear to interpret. After accounting for missing data, 244 DAST pretests, 236 DAST posttests, 252 DAET pretests, and 232 DAET posttests comprise the data set for the study.

Table 1

Overview of Participant Demographics

			School		Engineer		Cooperating Teacher	
Triad	**Grade**	**Class Size**	%Nonwhite	%Free/Reduced Lunch	Field	Gender	#Years Teaching	Master's Degree
15	3	25	48.6	55.0	Mechanical	M	21	Yes
22	3	21	56.0	85.5	Materials	F	14	Yes
24	4	23	48.6	55.0	Mechanical	M	22	Yes
25	4	25	43.1	39.7	Mechanical	M	8	No
32	3	24	21.6	42.1	Mechanical	M	11	Yes
34	5	24	86.8	38.6	Mechanical	M	10	Yes
41	3	25	46.7	76.4	Materials	F	6	Yes
42	3	24	25.6	24.6	Chemical	M	15	Yes
51	4	17	43.1	39.7	Materials	F	6	No
52	5	23	56.0	85.5	Chemical	M	5	No
53	4	24	38.4	72.9	Agricultural	F	5	No
56	4	21	69.0	80.4	Mechanical	M	14	No
58	4	24	69.0	80.4	Biochemical	F	10	No

Analysis

A qualitative content analysis approach (Schreier, 2012) was used to analyze the data, transforming the qualitative DAST and DAET responses into quantitative data via a coding process. The overarching objective was to create a coding system that could be applied to either a DAST or DAET response to indicate its alignment with science, engineering, or technology (see Figure 1).

Coding systems have been previously developed for the DAST (e.g., Farland-Smith, 2012; Finson et al., 1995) and for the DAET (e.g., Capobianco et al., 2011; Thomas et al., 2020; Weber et al., 2011). Approaches to assessing DAST responses have typically focused on quantifying the number of elements in a drawing that reflect stereotypes about scientists (Chambers, 1983; Finson et al., 1995; Flick, 1990; Huber & Burton, 1995). More recent coding systems characterize the activities represented in the drawings rather than just the number of stereotypical elements (e.g., Farland-Smith, 2012). Approaches to analyzing the DAET also aim to describe the activities represented in the responses, along with descriptive features such as the gender of the engineer, the tools used by the engineer, and the skin tone of the engineer (e.g., Capobianco et al., 2011; Fralick et al., 2009; Thomas et al., 2020; Weber et al., 2011). The coding system used by Fralick et al. (2009), for instance, describes the portrayed activities with codes such as observing, experimenting, explaining, and designing.

Although existing coding systems have utility, none were well-suited to addressing our research questions because our study takes a different focus than previous examinations of students' drawings. Characterizing the activity represented in a DAST/DAET response, as done by Farland-Smith (2012) and Fralick et al. (2009), is to some extent relevant to our study, but not sufficient for making the kinds of determinations needed to address our research questions. We therefore developed a new coding system for the purposes of the present study, built from the foundation of our conceptual framework. Importantly, the circumscribed focus of our study means that we did *not* attend to certain aspects of students' drawings that previous studies have examined. The coding system that we developed, for instance, did not seek to describe the race or gender of the scientist/engineer shown in the drawing, nor did it attempt to provide a global rating of "accuracy."

Coding Frame Development

Coding frame development began with a set of *a priori* codes that were grounded in the conceptual framework (summarized in Figure 1). For a given response (whether DAST or DAET), the initial coding frame categorized that response as aligned with either science, engineering, or technology. An "Interdisciplinary" code was also added to account for the possibility that a representation could show work that could be regarded as both science and engineering. A code of "None" was used for representations that showed an activity belonging to neither science, engineering, nor technology or portraying someone engaging in an activity unrelated to the goals of engineering or science. For instance, a portrayal of an everyday activity such as raking leaves would receive a code of "None." Although scientists and engineers might rake leaves, they do not do so as part of their scientific or engineering work. The initial coding frame is shown in Table 2. Note that the categories are mutually exclusive, and that the coding frame was designed to apply to either a DAST or DAET response.

The first and second authors iteratively tested and refined the initial coding frame by applying it to small subsets of the full data set. During each round of testing and refinement, the first two authors independently applied the coding frame and then met to compare codes and discuss issues that arose during coding. They tested and discussed each new coding frame until they encountered no drawings that could not be coded and reached a suitably high level of intercoder agreement during independent coding. Intercoder agreement was determined using Krippendorff's α (Krippendorff, 1970; 2004) because it accounts for chance agreements between the coders and can be used on categorical data such as those in the present study. For the final version of the coding frame, the value of α was 0.77 (Krippendorff, 2012; Schreier, 2012), indicating a high degree of interrater reliability. After establishing the final version of the coding frame, the first two authors applied it to the full data set.

Table 2

Initial Coding Frame

Category	Category Description
Science	A clear and unambiguous representation of scientific work. The person in the drawing is engaged in the study of natural phenomena or is developing explanations of the natural world.
Engineering	A clear and unambiguous representation of engineering work. The person in the drawing is engaged in technological design and development. The work is clearly distinguished from crafts work, tinkering with materials, or other skilled labor.
Technology	The person in the drawing is engaged in technological activity that is clearly **not** engineering work. Examples include routine repair and maintenance, construction work, or crafts work.
Interdisciplinary	The person in the drawing is engaged in work that simultaneously represents science and engineering.
None	The person in the drawing is doing something that falls outside the scope of any of the other categories. For instance, the scientist/engineer is teaching a group of children or reading a novel.

The final coding frame that emerged from the iterative process is summarized in Table 3, and examples of each of the assigned codes are shown in Figure 2.

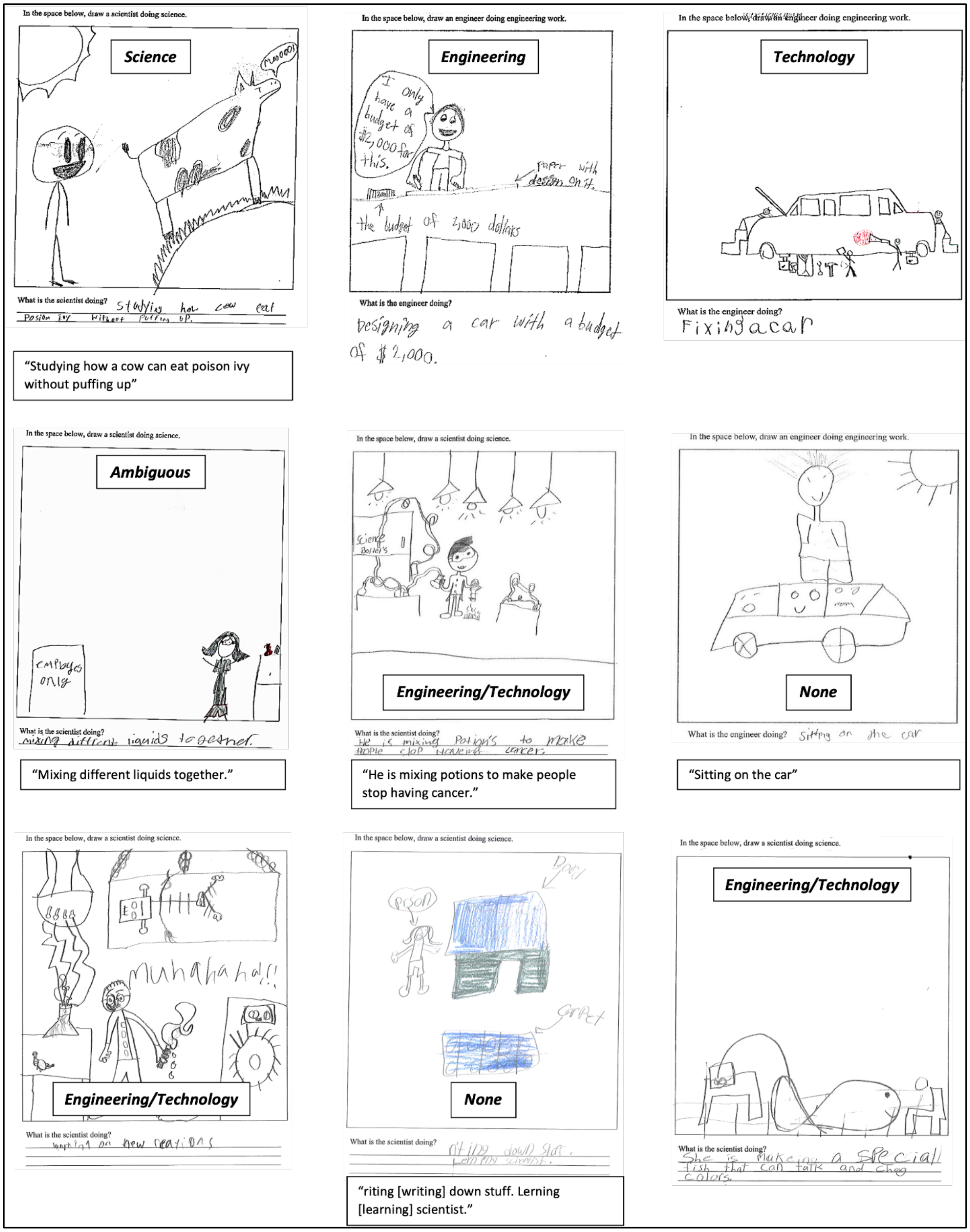
Table 3

Final Coding Frame

Category	Category Description
Science	A clear and unambiguous representation of scientific work. The person in the drawing is engaged in the study of natural phenomena or is developing explanations of the natural world.
Engineering	A clear and unambiguous representation of engineering work. The person in the drawing is engaged in technological design and development. The work is clearly distinguished from crafts work, tinkering with materials, or other skilled labor.
Technology	The person in the drawing is engaged in technological activity that is clearly **not** engineering work. Examples include routine repair and maintenance, construction work, or crafts work.
Ambiguous	The person in the drawing is engaged in activity that is sufficiently vague, that could potentially represent scientific, engineering, or technology work. Examples include "mixing chemicals" without any additional context, or "testing" something that is not described.
Engineering/ Technology	The person is engaged in work that is clearly **not science** and is consistent with either engineering **or** technology. More detail would be needed in order to definitively categorize the response as specifically "Technology" or "Engineering." Examples include making new inventions or "making potions."
None	The person in the drawing is doing something that falls outside the scope of any of the other categories. For instance, the scientist/engineer is teaching a group of children or reading a novel.

Figure 2

Representative Examples for Coding Categories



Several important modifications to the coding frame occurred during the refinement process. First, we found that many drawings showed a scientist or engineer engaged in a vaguely described activity that could potentially be consistent with science *or* engineering. For instance, many drawings showed a scientist/engineer "mixing chemicals" or "mixing liquids" in a laboratory. Without a clear and distinguishable intention for those activities, we could not categorize them as science or engineering. However, they also did not reflect "Interdisciplinary" work. A truly "Interdisciplinary" response would need to convey that *both* scientific and engineering goals were being pursued, but in the case of a vague and generic activity there was *no* clearly identifiable goal. We therefore created an "Ambiguous" code to account for those drawings. Although we found many instances of ambiguous drawings, we did not find any that were clear instances of interdisciplinary work. Although a part of our conceptual framework, the non-use of the "Interdisciplinary" code led us to eliminate it from our coding frame, consistent with our qualitative content analysis approach (Schreier, 2012).

An additional modification was made to account for the substantial number of drawings that showed individuals engaged in technological work that could not be unambiguously identified as engineering. As discussed in our conceptual framework, technological work or invention is not synonymous with engineering. New technologies can be utilized, modified, and developed by engineers, but also by tinkerers and craftspeople. In order for the creation of a novel technology to be a clear case of engineering, more contextual information would be needed. For example, several drawings depicted an individual "working on" or "making" a technology like a "robot" or some new "creation," but lacked any additional clarifying details. Without a clear goal or intention, we could not differentiate between an individual engaged in design (i.e., engineering) versus one engaged in building or fixing (i.e., non-engineering work). To account for those responses, we created the "Engineering/Technology" code. Importantly, this code differs from the "Ambiguous" code in that the response clearly does *not* represent science.

Capturing Emergent Patterns

Consistent with our qualitative content analysis approach (Schreier, 2012), during the process of developing our coding frame we were open and sensitive to emergent patterns in the data set. The emergent patterns described below are not directly related to our research questions but provide additional information about students' drawings that we reasoned might help us more fully interpret the results from our study. One pattern that we identified was a very high frequency of DAST responses showing a scientist working with chemicals. Those responses were assigned a range of codes, depending on what objectives the scientist was pursuing with the materials. For instance, as noted above, many responses were "Ambiguous" because they showed a scientist simply "mixing chemicals;" others showed a scientist using chemicals to create a medicine or "potion" of some kind (those responses were coded as "Engineering/Technology"). Even though representations of scientists working with chemicals could be aligned with different fields, we found the overall ubiquity of chemicals to be interesting in itself; we therefore decided to track its frequency on both the DAST and DAET.

We found a similarly ubiquitous representation on the DAET: a large number of students showed engineers working on vehicles – primarily cars, but also sometimes trains or airplanes. Most often, those representations showed the engineer as a mechanic and thus were coded as "Technology," but other codes were also possible if, for example, the engineer was shown engaged in the design of a vehicle rather than maintenance. Like representations of chemicals on the DAST, the ubiquity of vehicles on the DAET was interesting enough in itself that we also tracked its frequency on both the DAET and the DAST. Worth noting is that both of the emergent patterns identified here are consistent with prior research that used the DAST and DAET with young students (e.g., Capobianco et al., 2011; Finson, 2002; Fralick et al., 2009; Kelly, 2018; Thomas et al., 2020; Weber et al., 2011).

Quantitative Analysis of Coded Data

After all student DAST and DAET responses were coded, the proportion of pretest and posttest responses receiving each of the codes shown in Table 3 was determined for both instruments. For each instrument, statistically significant pretest-to-posttest changes in the proportion of responses assigned each code were determined using two-proportion *Z* Tests. For both instruments (pretest and posttest), we also calculated the proportion of responses that showed the common representations that emerged during our analysis: working with chemicals and working with cars.

Our research questions aim not to simply describe students' responses, but to assess the extent to which they align with the field in question. Table 4 summarizes the extent to which each of the assigned codes indicates alignment or misalignment for DAST and DAET responses.

Table 4

Extent of Alignment Indicated by Codes Assigned to DAST and DAET Responses

Assigned Code	DAST	DAET
Science	Fully Aligned	Misaligned
Engineering	Misaligned	Fully Aligned
Technology	Misaligned	Misaligned
Ambiguous	Partially Aligned	Partially Aligned
Engineering/Technology	Misaligned	Partially Aligned
None	Misaligned	Misaligned

The Ambiguous code is regarded as partially aligned for both instruments because it signifies a response that requires additional detail to determine whether it is a representation of science, engineering, or something else. The Engineering/Technology code is considered partially aligned for the DAET in that it signifies a response that has some elements of engineering while not being a clear case. Note that the Engineering/Technology code is **not** aligned for the DAST. To analyze the alignment of students' DAST and DAET responses, we determined the proportion of pretest and posttest responses that were Fully Aligned, Partially Aligned, and Misaligned. To compare the distribution of alignment levels from pretest to posttest, a Chi-Squared Test was conducted for both instruments. We also compared the distribution of alignment levels between the two instruments using a Chi-Squared Test.

The aggregate-level comparisons described above show which codes became more or less frequent from pretest to posttest, but they do not show what changes were actually occurring in individual students' responses. To provide a more in-depth examination of changes at the student level, a follow-up analysis was conducted using data only for students from whom we obtained linked pretest and posttest responses. Excluded from this analysis were three sets of classroom data (out of 13 total) in which the teachers removed student names from the drawings, but did not assign each student a unique identifier, thus making it impossible to link student pretest and posttest responses. After excluding those cases, 168 students had both pretest and posttest responses for the DAET, and 166 students had both for the DAST.

For each instrument, we tabulated how many students showed each possible "code shift," here defined as pretest-to-posttest change in assigned code (e.g., a change from the "Technology" code on the DAET pretest to an "Engineering" code on the DAET posttest). Because there were 6 codes that could be assigned to each response, a total of 36 different code shifts were possible (6 of which represent no change). To identify meaningful changes from pretest to posttest, we looked for code shifts with relatively high frequencies when compared to code shifts that occurred in the reverse direction (e.g., students who changed from "Technology" to "Engineering" versus students who changed from "Engineering" to "Technology").

Acknowledging the Limitations of Drawing Tasks

As we followed the analytical approach described above, we kept in mind several limitations that have been previously identified with drawing tasks. Researchers have emphasized that a single drawing does not necessarily reflect the full complexity of students' thinking (Bielenberg, 1997; Christidou et al., 2016; Finson, 2002; Samaras et al., 2012). Further, Reinisch et al. (2017) caution that assessing the accuracy of a given DAST response is challenging because scientists engage in a broad array of activities (Irzik & Nola, 2011) and therefore no one "ideal" DAST response exists. Engineers similarly engage in a broad range of activities (Pleasants & Olson, 2019a; 2019b). We designed our analysis to avoid the most significant of these limitations. Our analysis does not aim to fully characterize students' thinking about scientists and engineers, but rather to determine the extent to which their representations are aligned with different fields. Our coding frame allows for many different activities to potentially align with each field, thus addressing the concern raised by Reinisch et al. (2017). Further, we do not make overly expansive claims about students' knowledge of the nature of science or engineering based on their drawings; an accurately aligned representation is not necessarily indicative of a fully informed student. At the same time, a misaligned drawing is likely indicative of misconceptions.

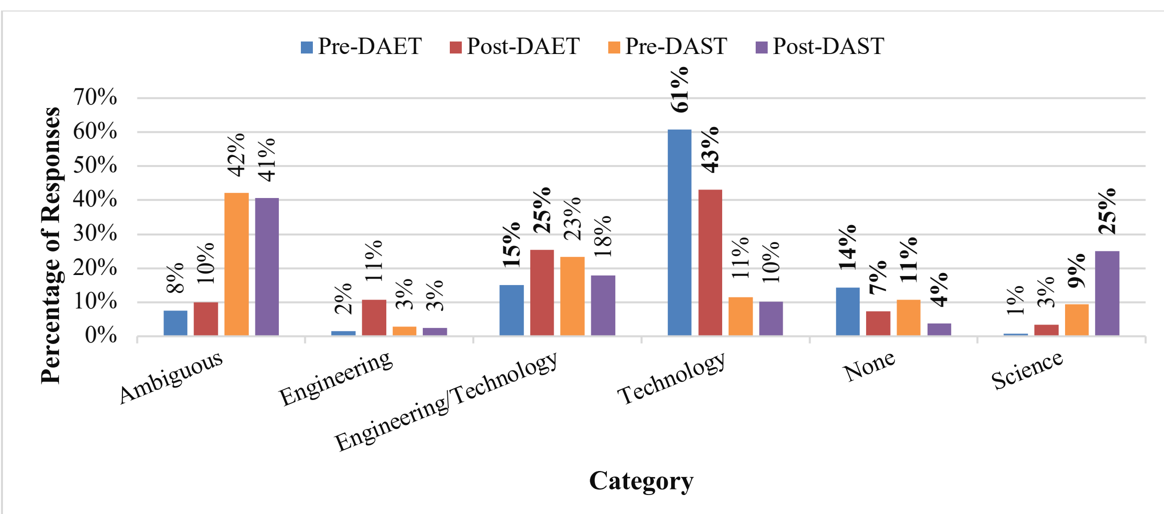
Results

Research Question 1: Alignment of Students' Representations with Science/Engineering

For each of the six possible codes that could be assigned to a student response, Figure 3 summarizes the percentage of responses that were assigned that code on each instrument for pretest and posttest.

Figure 3

Percentage of Student Responses Assigned Each Code



Note. Bolded percentages represent statistically significant changes from pre- to posttest based on a two-proportion Z test ($p < .05$).

Not surprisingly, a different overall pattern of codes can be seen for the DAST and the DAET. The Ambiguous code was common for the DAST on both pretest (42%) and posttest (41%) but rare for the DAET (8% of pretests and 10% of posttest). In contrast, the Technology code was common on the DAET for both pretest (61%) and posttest (43%), but relatively rare on the DAST (12% of pretests and 10% of posttests).

Table 5 summarizes the extent of alignment for students' responses on the DAET and DAST for pretest and posttest.

Table 5

Percentage of Student Responses at Each Alignment Level

	DAET (pre) n=252	DAET (post) n=232	DAST (pre) n=244	DAST (post) n=236
Fully Aligned	2%	11%	9%	25%
Partially Aligned	23%	35%	42%	41%
Misaligned	76%	54%	48%	34%

A Chi-Squared Test indicated that the pretest-to-posttest change in the distribution of alignments was statistically significant both for the DAET (X^2(df=2) = 32.7, p<.001) and the DAST (X^2(df=2) = 22.8, p<.001). On the pretest, fully aligned responses were rare for both instruments, but rose modestly from pretest to posttest. Similarly, on both instruments there was a modest decline in misaligned responses from pretest to posttest. We also compared the distribution of alignment levels between the two instruments and found a statistically significant difference in the distribution both at the time of pretest (X^2(df=2) = 43.7, p<.001) and posttest (X^2(df=2) = 22.8, p<.001). At both time points, students' responses showed an overall greater level of alignment on the DAST than they did on the DAET.

Pretest/Posttest Changes at the Student Level

Tables 6 and 7 summarize the code shifts that occurred for the DAET and the DAST, respectively.

Table 6

DAET – Number of Students with Each Pretest-to-Posttest Code Shift

	Posttest Code					
Pretest Code	Ambiguous	Engineering	Eng./Tech.	None	Science	Technology
Ambiguous	0	1	5	2	1	2*
Engineering	0	0	3	0	0	1
Eng./Tech.	5	3	8	1	1	9*
None	2	1	6	1	1	10
Science	0	0	1	0	0	0
Technology	12*	5	20*	8	5	54

Note. Shaded cells represent no code shift.
*These cells represent substantial net movements from pretest to posttest

Table 7

DAST – Number of Students with Each Pretest-to-Posttest Code Shift

Pretest Code	Posttest Code					
	Ambiguous	Engineering	Eng./Tech.	None	Science	Technology
Ambiguous	35	1	9*	1*	11	6
Engineering	1	0	3	0	1	0
Eng./Tech.	17*	1	14	2	4	5
None	8*	1	4	3	1	3
Science	10	0	1	1	4	2
Technology	5	0	5	0	2	5

Note. Shaded cells represent no code shift.
*These cells represent substantial net movements from pretest to posttest

Each cell gives the number of students showing each of the 36 possible code shifts that could have occurred from pretest to posttest. The shaded cells along the diagonal are instances where no shift occurred. For the DAET, 38% of responses received the same code on pretest and posttest, mostly in cases where the Technology code was assigned both times. For the DAST, 37% of student responses received the same code, typically in cases where both were coded as Ambiguous or Engineering/Technology. For students who *did* change codes, most notable are shifts that not only occurred with high frequency, but also occurred with a *greater* frequency than the reverse shift. Two such shifts occurred on the DAET: 12 students shifted from a Technology code to an Ambiguous code, whereas only two students shifted from Ambiguous to Technology; and 20 students shifted from Technology to Engineering/Technology, while only nine students showed the reverse. Both of those shifts represent a net increase in alignment in that both are from a misaligned code to a partially aligned one. These results indicate that the overall increase in alignment for the DAET (see Table 5) was driven in large part by the changes in these particular codes. For the DAST, two notable shifts were identified: 17 students shifted from Engineering/Technology (a misaligned code) to Ambiguous (a partially aligned code) while only nine showed the reverse shift. In addition, eight students shifted from a code of None (a misaligned code) to Ambiguous (a partially aligned one) while only one showed the reverse. Like the DAET, then, these results point to specific code shifts that played a large role in the increased alignment shown in Table 5.

Although the student-level analysis here gives insight into some of the code shifts that drove the overall increase in the alignment of students' responses, it does not fully explain the changes in alignment that were found. The two shifts identified for each instrument represent net movements from misaligned codes to partially aligned ones. However, there was no singular code shift that accounted for the increase in fully aligned codes. That is, for students who shifted to Engineering on the DAET posttest or Science on the DAST posttest, there was no clear pattern in terms of which codes they came from on the pretest. One point to emphasize when interpreting this part of the analysis is that the alignments in Table 5 utilize all student responses, whereas Tables 6 and 7 show only a subset of responses from students who had complete sets of linked data.

Research Question 2: Evidence of Conflation in Students' Representations

As noted above, the overall pattern of codes assigned to students' responses differed between the DAET and the DAST (see Figure 3). In aggregate, therefore, students do seem to perceive differences between the two fields. That result is further supported by examining the two common representations that emerged during our coding process: working with cars and working with chemicals. Table 8 shows the percentage of responses that showed those common representations for each instrument, which indicate that students associate scientists and engineers with different sorts of materials.

Table 8

Percentage of Student Responses Showing Common Representations

	DAET (pre) n=252	DAET (post) n=232	DAST (pre) n=244	DAST (post) n=236
Working with Chemicals	1%	0%	52%	57%
Working with Vehicles	42%	24%	2%	2%

However, even though students do not necessarily view engineering and science as identical, cause for concern still exists regarding the issue of conflation, particularly in students' representations of scientists. In the case of their representations of engineers, very few instances occurred where students' DAET responses showed scientific work (1% of pretests and 3% of posttests). In contrast, although students' DAST responses were rarely coded as Engineering (3% on both pretest and posttest), they were often coded as Engineering/Technology: 23% of pretests and 18% of posttests received that code, a change that was not statistically significant (p = .131; see Figure 3). The Engineering/Technology code was typically applied to instances of portrayals of scientists as inventors, rather than as investigators of the natural world. While invention is not necessarily engineering, it is an activity that is better aligned with engineering than with science. Consistent with the patterns in Table 8, students often depicted scientists inventing *with chemicals*, whereas chemicals were largely absent from students' representations of engineers. Yet even if students associate scientists with different *materials* than engineers (a dubious distinction, given that chemical engineering exists), the fact that many students conceptualize both as being involved in technological development is evidence of conflation.

Discussion

Prior studies of students' drawings of scientists and engineers have established the existence of multiple misunderstandings and stereotypes (Capobianco et al., 2011; Christidou et al., 2016; Finson, 2002; Fralick et al., 2009; Huber & Burton, 1995; Kelly, 2018; Sharkawy, 2012). Those common misrepresentations emerged in the present study as well, but the goal of the present work was not to replicate or confirm those well-established patterns. Rather, our investigation extends research on the DAST and DAET in multiple ways. First, we focus on the extent to which elementary students' representations of scientists and engineers are accurately aligned with the kinds of work done in those fields—an important issue given that science and engineering are now being taught in the same classroom space, possibly even in the context of integrated "STEM" (Kelley & Knowles, 2016; Moore et al., 2015; NRC, 2012; 2014). Second, unlike prior studies, we conducted a side-by-side comparison of students' DAST and DAET responses. Third, we explored how those responses changed after the students experienced a semester of science instruction that included engineering design activities as well as interactions with an engineer through a triad teaching model.

We found that students' drawings showed more accurate representations of scientists than of engineers, both at the time of pretest and posttest. That result is perhaps not surprising, as young students are not likely to have had much contact with engineers or the field of engineering either in or out of school (Capobianco et al., 2011; Fralick et al., 2009; NAE & NRC, 2008; 2009). For students in the present study, the engineering instruction they received during the project was generally their first such educational exposure to engineering. The better alignment found in students' DAST responses might therefore be attributed primarily to the larger number of experiences students have had learning about science and scientists both in and out of school. Of course, such experiences do not necessarily result in *fully accurate* views about science (Clough, 2006; Kelly, 2018; Finson, 2002; Sharkawy, 2012). We emphasize that even though students' representations of scientists were *better* aligned than their representations of engineers, their *overall* alignment was relatively low. Students in our study showed many of the same misunderstandings about science (and engineering) that appear in previous research.

We found an overall increase in alignment from pretest to posttest on both the DAST and the DAET. Those increases, however, were relatively modest. Even on the posttest, very few students produced representations that were completely aligned with the targeted field, especially on the DAET (only 11% of posttest responses). Much more common than fully aligned responses were partially aligned ones. The student-level analysis of code shifts from pretest to posttest also showed that the largest net movements on both instruments were from misaligned codes to partially aligned codes. While partially aligned responses do not show overtly erroneous ideas, their ambiguities mean that they are not necessarily indicative of accurate conceptions of science or engineering. Thus, while students might have let go of certain misconceptions about science and engineering, they might not have replaced them with views that are fully accurate or that enable distinctions to be made.

Although the increases in alignment were modest, the fact that they occurred across both instruments is interesting given that the project involved interactions with a graduate student in *engineering*, not science. Most likely, the gains in alignment are attributable to certain components of our professional development project. Like many projects that form partnerships between teachers and STEM professionals (e.g., Houseal et al., 2014; Mitchell et al., 2003; Thompson & Lyons, 2008), an overt goal of our project was for the engineers to serve as ambassadors of their field and communicate to both the teachers and students the kind of work that engineers do. Throughout the professional development activities, we also emphasized to both the teachers and engineers the importance of helping students recognize the differences between science and engineering. The triads did work toward those objectives to some extent. The time when triads most deliberately addressed those ideas was near the beginning of the semester, when the engineers introduced students to the details of their own work. Those presentations typically included the most substantive discussions about the nature of engineering and how science is important for engineering work.

However, the majority of students' contact with engineering over the course of the semester came in the form of the engineering activities in which they participated. In prior examinations of those activities, we found that the teachers and engineers rarely engaged students in conversations about the nature of engineering or science; in the few instances that conversations did occur, they were typically very brief (Pleasants, 2018; Pleasants & Olson, 2021). Thus, students were mostly left to draw their own conclusions about the nature of those fields based on their classroom experiences. Research makes clear that in such situations, the conclusions that students draw will not necessarily be accurate ones (Clough, 2006; Lederman & Lederman, 2014; McComas et al., 2020). Thus, the somewhat limited ways that the teachers and engineers addressed the nature of science and engineering with their students are likely to account for both the overall gains in alignment, as well as the modest size of those gains.

The present work was motivated by the concern that students could potentially conflate science and engineering, especially after experiencing engineering lessons alongside science instruction (McComas & Nouri, 2016). That concern was only somewhat borne out by our results. The pattern of codes assigned to students' DAST responses differed substantially from those assigned to their DAET responses, and we found very few instances where students represented scientists engaged in engineering or vice-versa. We also found that students tended to associate scientists and engineers with different materials (chemicals for scientists and vehicles for engineers). Those results indicate that while students may not hold accurate views of scientists and engineers, they do not view the two as being one and the same.

We did, however, find one avenue of potential conflation in that a significant proportion of students showed scientists engaged in the invention or creation of new technologies (approximately one fifth of responses on pretest and posttest), an activity more accurately associated with engineers. The view of scientists as inventors is consistent with images of the "mad scientist" that often appear on the DAST and that are pervasive in the media (Finson, 2002, Kelly, 2018). It is a problematic perspective because it wrongly conveys that both scientists and engineers are largely concerned with the same thing: creating novel technologies. Even if students associate scientists and engineers with different materials (i.e., scientists invent things using chemicals, whereas engineers invent machines), that difference is neither an accurate one nor does it avoid the conflation problem. Importantly, though, we did not find that the percentage of students showing this problematic conception *changed* from pretest to posttest. It is therefore unlikely that the notion was *caused* by the incorporation of engineering into their science instruction. Rather, it is a pre-existing and persistent conception, given that it was not *improved* by the instruction that students received.

Limitations and Future Directions

Drawing tasks such as the DAST and DAET have inherent limitations that restrict our ability to make claims about how students conceptualize science and engineering. Drawing tasks do not necessarily elicit the full complexity of students' ideas about scientists or engineers (Bielenberg, 1997; Christidou et al., 2016; Reinisch et al., 2017). The reasoning underlying what students choose to draw is also inevitably hidden from the view of the researcher (Finson, 2002).

Despite the limitations, we used the DAST and DAET in this study largely because alternative research tools are lacking. Many instruments exist to probe students' views of the nature of science (Abd-El-Khalick, 2014), but there are few extant methods for examining students understanding of the nature of engineering and, more importantly, their understanding of the differences between science and engineering. Interviewing students (e.g., Karatas et al., 2011) can provide more in-depth views of their thinking but is impractical for studies with large numbers of students, such as the present one. This issue could be mitigated by conducting follow-up interviews with a subsample of students after administering the DAST or DAET. This approach has been suggested by other researchers as a way to validate the interpretations of student drawings (e.g., Hammack et al., 2020; Reinisch et al., 2017). Even more valuable would be an instrument that more directly elicits students' thinking about the differences between science and engineering. An instrument that tasks students with categorizing (rather than generating) different STEM-related activities, for instance, is a potentially fruitful option that has already been shown to be insightful within nature of science research (Walls, 2012).

Another limitation of our study is that it occurred within the context of a resource-intensive professional development project. The educational experiences provided to the students in the study are therefore not representative of typical elementary classrooms. Elementary teachers who incorporate engineering into their science instruction are unlikely to receive extensive professional development support (Banilower, 2019), and are especially unlikely to have access to an expert in engineering. Thus, future research ought to examine how students in more typical classroom conditions, develop in their understanding of scientists and engineers as engineering is incorporated into science instruction.

Conclusions & Implications

Including engineering as part of science instruction will not necessarily result in issues of conflation, nor will it, by itself, assist students in making sense of the nature of engineering or science. Helping students to develop more accurate views about the nature of science and engineering, and particularly the ways in which the two fields differ, requires explicit instruction (Lederman & Lederman, 2014; McComas et al., 2020). Engaging students in engineering activities does create opportunities for teachers to have explicit conversations about what engineering is and how it differs from science. Teachers ought to draw students' attention to how the goals of an engineering design activity are different from a science inquiry activity. The materials might be similar, and students might also use similar techniques in both, but the purposes are not the same. Such explicit conversations would do much to address the misunderstandings that were found in the present study.

Bringing STEM experts into the classroom creates further opportunities to help students develop more accurate views of science and engineering. STEM experts, such as the engineering graduate students in the present study, have knowledge and experiences that can help students connect classroom activities to the real world of disciplinary practice. They can share examples of their own work and use those examples to highlight key features of how science and engineering work, how they are related, but also how they are different ways of knowing. However, all of those promising possibilities can easily become *missed opportunities*; this was largely what occurred in the present study. Unless explicit conversations are had about the nature of disciplinary work, mere proximity to and interactions with STEM experts will not be sufficient (Sadler et al., 2010). Projects that bring STEM experts into science classrooms should prepare them to have productive conversations about the nature of science and engineering and find ways to ensure that those conversations take place.

This work was supported by the National Science Foundation award #11440446. The authors would like to thank all of the teachers and engineers who participated in this project. We would also like to thank Emily Dux and Aubrey Dawson for their contributions to the research work.

Jacob Pleasants (Jacob.Pleasants@ou.edu) is an assistant professor of science education at the University of Oklahoma. He has been working to prepare pre-service and in-service science teachers for nearly ten years. His research focuses on communicating the nature of science and engineering in K-12 classrooms.

Iliana De La Cruz (idelacruz1@tamu.edu) is a doctoral student at Texas A&M University. Her time in graduate school has been mostly dedicated to studying results from integrating engineering in science education. Her research focuses on reform efforts effects on accessible science teaching.

Joanne K. Olson (jkolson@tamu.edu) is a professor in science education, the acting Department Head for Teaching, Learning & Culture, and the former president of the Association for Science Teacher Education. Her research efforts focus on: 1) science teacher preparation; 2) the inclusion of engineering in elementary science standards and how "STEM" is addressed by teachers and teacher education programs; 3) the nature of science and nature of engineering and their role in improving STEM education; 4) philosophical underpinnings of teacher education and their role in curriculum design and pedagogical practices.

References

American Society for Engineering Education. (2020). *Framework for P-12 engineering learning: A defined and cohesive educational foundation for P-12 engineering.* American Society for Engineering Education. https://p12framework.asee.org/wp-content/uploads/2020/11/Framework-for-P-12-Engineering-Learning-1.pdf

Banilower, E. R. (2019). Understanding the big picture for science teacher education: The 2018 NSSME+. *Journal of Science Teacher Education, 30*(3), 201–208. https://doi.org/10.1080/1046560X.2019.1591920.

Barman, C. R. (1999). Students' views about scientists and school science: Engaging K–8 teachers in a national study. *Journal of Science Teacher Education*, *10*(1), 43–54. https://www.jstor.org/stable/43156207

Bielenberg, J. E. (1997). *Learning from practice: Impressions from pictures of scientists don't tell the whole story* (Report No. SE059827). National Association for Research in Science Teaching. https://eric.ed.gov/?id=ED406165

Bucciarelli, L. (1994). *Designing engineers.* MIT Press.

Bucciarelli, L. (2009). Engineering science. In J. K. B. Olsen, S. A. Pedersen, & V. F. Hendricks (Eds.), *A companion to the philosophy of technology* (pp. 66-69). Blackwell Publishing.

Capobianco, B. M., Diefes-dux, H. A., Mena, I., & Weller, J. (2011). What is an engineer? Implications of elementary school student conceptions for engineering education. *Journal of Engineering Education*, *100*(2), 304–328. https://doi.org/10.1002/j.2168-9830.2011.tb00015.x

Chambers, D. W. (1983). Stereotypic images of the scientist: The Draw-a-Scientist Test. *Science Education*, *67*(2), 255–265. http://doi.wiley.com/10.1002/sce.3730670213

Chou, P., & Chen, W. (2017). Elementary school students' conceptions of engineers: A drawing analysis study in Taiwan. *International Journal of Engineering Education, 33*(1), 476–488. http://doi.wiley.com/10.1002/sce.3730670213

Christidou, V., Bonoti, F., & Kontopoulou, A. (2016). American and Greek children's visual images of scientists. *Science & Education*, *25*(5–6), 497–522. https://link-springer-com.ezproxy.library.tamu.edu/content/pdf/10.1007%2Fs11191-016-9832-8.pdf

Clough, M. P. (2006). Learners' responses to the demands of conceptual change: Considerations for effective nature of science instruction. *Science & Education*, *15*(5), 463–494. https://www.doi.org/10.1007/s11191-005-4846-7

Dusek, V. (2006). *Philosophy of technology: An introduction.* Blackwell.

Dym, C. L., & Brown, D. (2012). *Engineering design: Representation and reasoning* (2nd ed.). Cambridge University Press.

Farland-Smith, D. (2012). Development and field test of the modified draw-a-Scientist Test and the draw-a-Scientist rubric. *School Science and Mathematics, 112*(2), 109–116. http://doi.wiley.com/10.1111/j.1949-8594.2011.00124.x

Fetters, M. D., Curry, L. A., & Creswell, J. W. (2013). Achieving integration in mixed methods designs—principles and practices. *Health Services Research*, *48*(6), 2134-2156.

Finson, K. D. (2002). Drawing a scientist: What we do and do not know after fifty years of drawings. *School Science and Mathematics*, *102*(7), 335–345. http://doi.wiley.com/10.1111/j.1949-8594.2002.tb18217.x

Finson, K. D., Beaver, J. B., & Cramond, B. L. (1995). Development and field test of a checklist for the draw-a-scientist rest. *School Science and Mathematics*, *95*(4), 195–205. http://doi.wiley.com/10.1111/j.1949-8594.1995.tb15762.x

Flick, L. (1990). Scientist in residence program improving children's image of science and scientists. *School Science and Mathematics*, *90*(3), 204–214. https://doi.org/10.1111/j.1949-8594.1990.tb15536.x

Fralick, B., Kearn, J., Thompson, S., & Lyons, J. (2009). How middle schoolers draw engineers and scientists. *Journal of Science Education and Technology*, *18*(1), 60–73. https://doi.org/10.1007/s10956-008-9133-3

Hammack, R., Utley, J., Ivey, T., & High, K. (2020). Elementary teachers' mental images of engineers at work. *Journal of Pre-College Engineering Education Research (J-PEER), 10*(2), Article 3. https://doi.org/10.7771/2157-9288.1255

Hoddeson, L., Henriksen, P. W., Meade, R. A., & Westfall, C. (1993). *Critical assembly: A technical history of Los Alamos during the Oppenheimer years, 1943-1945*. Cambridge University Press.

Houkes, W. (2009). The nature of technological knowledge. In A. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 309–350). North-Holland. https://doi.org/10.1016/B978-0-444-51667-1.50016-1

Houseal, A. K., Abd-El-Khalick, F., & Destefano, L. (2014). Impact of a student–teacher–scientist partnership on students' and teachers' content knowledge, attitudes toward science, and pedagogical practices. *Journal of Research in Science Teaching*, *51*(1), 84-115. https://doi.org/10.1002/tea.21126

Huber, R. A., & Burton, G. M. (1995). What do students think scientists look like? *School Science and Mathematics*, *95*(7), 371–376. https://doi.org/10.1111/j.1949-8594.1995.tb15804.x

Ihde, D. (2009). Technology and science. In J. K. B. Olsen, S. A. Pedersen, & V. F. Hendricks (Eds.), *A companion to the philosophy of technology* (pp. 51-60). Blackwell Publishing. http://dx.doi.org/10.1002%2F9781444310795.ch8

International Technology and Engineering Education Association. (2020). *Standards for technological and engineering literacy: The role of technology and engineering in STEM education*. ITEEA.

Irzik, G., & Nola, R. (2011). A family resemblance approach to the nature of science for science education. *Science & Education*, *20*(7–8), 591–607. https://doi.org/10.1007/s11191-010-9293-4

Karatas, F. O., Micklos, A., & Bodner, G. M. (2011). Sixth-grade students' views of the nature of engineering and images of engineers. *Journal of Science Education and Technology, 20*(2), 123–135. https://doi.org/10.1007/s10956-010-9239-2

Kelley, T. R., & Knowles, J. G. (2016). A conceptual framework for integrated STEM education. *International Journal of STEM Education, 3*(1), 1–11. https://doi.org/10.1186/s40594-016-0046-z

Kelly, L. (2018). Draw a scientist. *Science and Children*, *56*(4), 86-90. https://www.nsta.org/draw-scientist

Knight, M., & Cunningham, C. (2004). Draw an engineer test (DAET): Development of a tool to investigate students' ideas about engineers and engineering. *Proceedings of American Society for Engineering Education Annual Conference and Exposition* (Vol. 111, pp. 4079–4089). ASEE. https://doi.org/10.18260/1-2--12831

Krippendorff, K. (1970). Bivariate agreement coefficients for reliability data. In E. R. Borgatta & G. W. Bohrnstedt (Eds.), *Sociological methodology* (pp. 139-150). Jossey Bass. https://doi.org/10.2307/270787

Krippendorff, K. (2004). Reliability in content analysis: Some common misconceptions and recommendations. *Human Communication Research*, *30*(3), 411-433. https://doi.org/10.1111/j.1468-2958.2004.tb00738.x

Krippendorff, K. (2012). *Content analysis: An introduction to its methodology*. Sage Publications.

Kroes, P. (2012). *Technical artefacts; Creations of mind and matter: A philosophy of engineering design* (1st ed., Vol. 6). Springer Netherlands.

Lachapelle., C. P., & Cunningham, C. M. (2007). Engineering is elementary: Children's changing understandings of science and engineering. *Proceedings of American Society for Engineering*

Education Annual Conference & Exposition (Vol. 114, pp. 6401–6433). ASEE. https://doi.org/10.18260/1-2--1470

Lachapelle, C. P., & Cunningham, C. M. (2014). Engineering in elementary schools. In S. Purzer, J. Strobel, & M. E. Cardella (Eds.), *Engineering in pre-college settings: Synthesizing research, policy, and practices* (pp. 61–88). Purdue University Press. https://www.researchgate.net/profile/Cathy-Lachapelle/publication/279930977_Engineering_in_Elementary_Schools/links/56e03efc08aee77a15fe8fb2/Engineering-in-Elementary-Schools.pdf

Lawrence Hall of Science (2015). *Full option science system: Next generation*. Delta Education.

Lederman, N.G., & Lederman, J.S. (2014). Research on teaching and learning of nature of science. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of Research on Science Education, Vol. II* (pp. 600–620). Lawrence Erlbaum Associates.

Losh, S. C., Wilke, R., & Pop, M. (2008). Some methodological issues with "draw a scientist tests" among young children. *International Journal of Science Education*, *30*(6), 773–792. https://doi.org/10.1080/09500690701250452

Luo, T., So, W. W. M., Wan, Z. H., & Li, W. C. (2021). STEM stereotypes predict students' STEM career interest via self-efficacy and outcome expectations. *International Journal of STEM Education, 8*(1), 1-13. https://doi.org/10.1186/s40594-021-00295-y

McComas, W. F., & Burgin, S. R. (2020). A critique of "STEM" education. *Science & Education*, *29*(4), 805-829. https://doi.org/10.1007/s11191-020-00138-2

McComas, W. F. & Clough, M. P. (2020). Nature of science in science instruction: Meaning, advocacy, rationales and recommendations. In W. F. McComas (Ed.) *Nature of science in science instruction: Rationales and strategies* (pp. 3-22). Springer. https://doi.org/10.1007/978-3-030-57239-6_1

McComas, W. F., Clough, M. P. & Nouri, N. (2020). Nature of science and classroom practice: A review of the literature with implications for effective NOS instruction. In W. F. McComas (Ed.) *Nature of science in science instruction: Rationales and strategies* (pp. 67-111). Springer. https://doi.org/10.1007/978-3-030-57239-6_4

McComas, W. F., & Nouri, N. (2017). The nature of science and the Next Generation Science Standards: analysis and critique. *Journal of Science Teacher Education*, *27*(5), 555–576. https://doi.org/10.1007/s10972-016-9474-3

Mead, M., & Metraux, R. (1957). Image of the scientist among high–school students. *Science, 126*(3270), 384–390. https://doi.org/10.1126/science.126.3270.384

Mitcham, C. (1994). *Thinking through technology: The path between engineering and philosophy*. University of Chicago Press.

Mitcham, C., & Schatzberg, E. (2009). Defining technology and the engineering sciences. In A. Meijers (Ed.), *Philosophy of technology and engineering sciences* (pp. 27–63). Elsevier. https://doi.org/10.1016/B978-0-444-51667-1.50006-9

Mitchell, J., Levine, R., Gonzalez, R., Bitter, C., Webb, N., & White, P. (2003, April 21-25). Evaluation of the National Science Foundation graduate teaching fellows in K-12 education (GK-12) program [Conference presentation]. American Education Research Association Annual Meeting, Chicago, IL, United States.

Montfort, D. B., Brown, S., & Whritenour, V. (2013). Secondary students' conceptual understanding of engineering as a field. *Journal of Pre-College Engineering Education Research*, *3*(2), 1–12. https://doi.org/10.7771/2157-9288.1057

Moore, T. J., Tank, K. M., Glancy, A. W., & Kersten, J. A. (2015). NGSS and the landscape of engineering in K-12 state science standards. *Journal of Research in Science Teaching*, *52*(3), 296–318. https://doi.org/10.1002/tea.21199

Museum of Science, Boston. (2007). *Engineering is elementary*. Museum of Science.

National Academy of Engineering, & National Research Council. (2008). *Changing the conversation: Messages for improving public understanding of engineering.* National Academies Press. https://nsf.gov/attachments/111302/public/4-Pearson.pdf

National Academy of Engineering, & National Research Council. (2009). *Engineering in K-12 education: Understanding the status and improving the prospects*. National Academies Press.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Newberry, B. (2013). Engineered artifacts. In D. P., Michelfelder, N., McCarthy, & E. Goldberg, (Eds.), *Philosophy and engineering: Reflections on practice, principles and process* (pp. 165–176). Springer. https://doi.org/10.1007/978-94-007-7762-0_13

NGSS Lead States. (2013). *Next generation science standards: For states, by states.* The National Academies Press.

Pigliucci, M. (2013). The demarcation problem. A (belated) response to Laudan. In M. Pigliucci & M. Boudry (Eds.), *Philosophy of pseudo-science: Reconsidering the demarcation problem* (pp. 9-28). University of Chicago Press.

Pitt, J. C. (1995). Discovery, telescopes, and progress. In J. C. Pitt (Ed.), *New directions in the philosophy of technology* (pp. 1–16). Springer. https://doi.org/10.1007/978-94-015-8418-0_1

Pleasants, J. (2018). *Engineering in the elementary science classroom: Teachers' knowledge and practice of the nature of engineering.* [Doctoral Dissertation, Iowa State University]. ProQuest Dissertations Publishing.

Pleasants, J. (2020). Inquiring into the nature of STEM problems: Implications for pre-college education. *Science & Education, 29*(4), 831-855. https://doi.org/10.1007/s11191-020-00135-5

Pleasants, J., & Olson, J. K. (2019a). What is engineering? Elaborating the nature of engineering for K-12 education. *Science Education, 103*(1), 145-166. https://doi.org/10.1002/sce.21483

Pleasants, J., & Olson, J. K. (2019b). Refining an instrument and studying elementary teachers' understanding of the scope of engineering. *Journal of Pre-College Engineering Education Research, 9*(2), 1-18. https://doi.org/10.7771/2157-9288.1207

Pleasants, J., & Olson, J. K. (2021). *Elementary teachers' scaffolding of engineering practices: Issues with 'the engineering design process' as instructional model* [Paper presentation]. NARST International Conference, Virtual.

Reinisch, B., Krell, M., Hergert, S., Gogolin, S., & Krüger, D. (2017). Methodical challenges concerning the draw-a-scientist test: A critical view about the assessment and evaluation of learners' conceptions of scientists. *International Journal of Science Education*, *39*(14), 1952–1975. https://doi.org/10.1080/09500693.2017.1362712

Roehrig, G. H., Dare, E. A., Ellis, J. A., & Ring-Whalen, E. (2021). Beyond the basics: a detailed conceptual framework of integrated STEM. *Disciplinary and Interdisciplinary Science Education Research*, *3*(1), 1-18. https://doi.org/10.1186/s43031-021-00041-y

Rynearson, A. M. (2016). *From mechanic to designer: Evolving perceptions of elementary students over three years of engineering instruction* [Doctoral dissertation, Purdue University]. Purdue University Repository. https://docs.lib.purdue.edu/dissertations/AAI10179099/

Sadler, T. D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching*, *47*(3), 235-256. https://doi.org/10.1002/tea.20326

Samaras, G., Bonoti, F., & Christidou, V. (2012). Exploring children's perceptions of scientists through drawings and interviews. *Procedia–Social and Behavioral Sciences*, *46*, 1541–1546. https://doi.org/10.1016/j.sbspro.2012.05.337

Schibeci, R. A. (1986). Images of science and scientists and science education. *Science Education*, *70*(2), 139–149. https://doi.org/10.1002/sce.3730700208

Sharkawy, A. (2012). Exploring the potential of using stories about diverse scientists and reflective activities to enrich primary students' images of scientists and scientific work. *Cultural Studies of Science Education*, *7*(2), 307–340. https://doi.org/10.1007/s11422-012-9386-2

Schreier, M. (2012). *Qualitative content analysis in practice.* Sage Publications.

Teddlie, C., & Tashakkori, A. (2009). *Foundations of mixed methods research: Integrating quantitative and qualitative approaches in the social and behavioral sciences.* Sage.

Thomas, J., Hawley, L. R., & DeVore-Wedding, B. (2020). Expanded understanding of student conceptions of engineers: Validation of the modified draw-an-engineer test (mDAET) scoring rubric. *School Science and Mathematics*, *120*(7), 391-401. https://doi.org/10.1111/ssm.12434

Thompson, S., & Lyons, J. (2008). Engineers in the classroom: Their influence on African-American students' perceptions of engineering. *School Science and Mathematics, 108*(5), 197–210. https://doi.org/10.1111/j.1949-8594.2008.tb17828.x

Vincenti, W. (1990). *What engineers know and how they know it.* Johns Hopkins University Press.

Volti, R. (2005). *Society and technological change.* Macmillan.

Walls, L. (2012). Third grade African American students' views of the nature of science. *Journal of Research in Science Teaching*, *49*(1), 1-37. https://doi.org/10.1002/tea.20450

Weber, N., Duncan, D., Dyehouse, M., Strobel, J., & Diefes-Dux, H. A. (2011). The development of a systematic coding system for elementary students' drawings of engineers. *Journal of Pre-College Engineering Education Research*, *1*(1), 49–62. https://doi.org/10.7771/2157-9288.1030

Zeidler, D. L., Herman, B. C., Clough, M. P., Olson, J. K., Kahn, S., & Newton, M. (2016). Humanitas emptor: Reconsidering recent trends and policy in science teacher education. *Journal of Science Teacher Education*, *27*(5), 465-476.

Appendix: DAST and DAET Instruments

Name: ______________________________

In the space below, draw a scientist doing science.

What is the scientist doing?

Name:___________________

In the space below, draw an engineer doing engineering work.

What is the engineer doing?