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Development and Validation of the Draw-an-Engineer and Applications of Mathematics and Science Instrument (Work in Progress)

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Introduction

A Framework for K-12 Science Education [1] and the *Next Generation Science Standards* (NGSS) [2] highlight the importance of including engineering in the K-12 curriculum. The implementation of NGSS requires that teachers understand engineers' use of design in their work as well as the ways that engineering is connected to science, technology, and society. The ways in which an engineer's work connects to science, technology, and society is dependent upon the specific context in which they are working, and offering students opportunities to engage with problems situated within realistic engineering contexts can help students meaningfully learn mathematics and science [3]. Providing these opportunities for students will require teachers to have an understanding of the work of engineers and the way that work connects to science and mathematics. Thus, the aim of the current study was to examine the use of the Draw-An-Engineer and Applications of Mathematics and Science (DEAMS) instrument and associated scoring rubric (DEAMS-R) for eliciting elementary teachers' perceptions about the work of engineers and the ways that engineers use mathematics and science.

Background Literature

Engineering Education

Engineering education has become increasingly prevalent in elementary schools during the years since the release of NGSS. Engaging in engineering learning activities can be a means for students to learn mathematics and science and make connections between school science and mathematics and real world science and mathematics[3]. One area where there is still much to be gleaned, however, is how teachers can meaningfully connect school science and mathematics concepts to realistic engineering problems. While engineering is inherently interdisciplinary [4], teachers often struggle with how to connect engineering to mathematics and science standards [5]. To do this, teachers will need to have knowledge of the work of engineers and the ways engineers use mathematics and science in their work.

Use of Drawing Instruments

For nearly a century, educational researchers have utilized drawings from instruments such as the Draw-A-Man test [6] as a means to assess individuals' mental images. Later iterations of this instrument evolved with more specific foci such as the Draw-A-Scientist test [7], [8] and the Draw-An-Engineer test (DAET) [9]. Many studies using DAET find that respondents provide drawings of white, male engineers who are solitary and are builders and fixers of things [10] – [14]. Recent studies on DAET often focus on the prevalence of the gender of the engineer drawn by the participants (e.g., [15], [10]). Other studies have used the DAET to examine children's understanding of the Nature of Engineering [12]. Recently, Authors [16] developed the mDAET to explore elementary students' knowledge and understanding of the work of engineers with a focus on how mathematics and science are used by engineers. Overall, a general consensus of these studies is that children hold stereotypical views of engineers and their work.

Infrequently, researchers have used versions of the DAET to identify K-12 teachers' perceptions of engineers [17] – [19]. The literature suggests that teachers hold similar stereotypical misconceptions as children [17] and that relatively few teachers include drawings that indicate a connection between engineering and society [18]. Pleasants et al. [19] used DAET to assess whether participating in an engineering-focused PD program altered elementary teachers' representation of engineers and their understanding of the engineering design process. Authors [20] found that rubrics designed for use with children's drawings do not adequately capture adult conceptions, suggesting the need for a rubric designed for use with adults. Looking beyond the engineering design process, the present study uses a modified version of the DAET to assess preservice elementary teachers' conceptions of the work of engineers and how engineers use mathematics and science in their work.

Mental Model Theory

A mental model is how an individual mentally represents real or imaginary situations [21], [22]. This idea was first postulated by Craik [23], who suggested that individuals carry in their minds these mental models of how their world works. Further, Doyle and Ford [24] proposed that "the structure of mental models 'mirrors' the perceived structure of the external system being modelled" (p. 17). This research is grounded in both mental model theory and in the use of drawings as a way to capture elementary teachers' views of the work of an engineer. Teachers create a mental model of their understanding of the work of engineers based on prior knowledge and past experiences and the use of drawings allows teachers to "reconstruct and assimilate the experiences they have had" [25] (p. 1).

Methods

Participants

Participants included 24 undergraduate students enrolled in an elementary education teacher certification program at a large, public land-grant university in the western United States. Participants were primarily white (96%), female identifying (91%), and in their twenties (91%). Each of the 24 participants completed the instrument two times, for a total of 48 completed drawings and associated answers to the written prompts.

Data Collection

The Draw-An-Engineer and Applications of Mathematics and Science Instrument (DEAMS) is administered with a single 11"x 14" piece of paper. First, participants were instructed to "Draw a picture of an engineer(s) engaging in their daily work. Include a speech bubble that tells about what they are doing." Next, participants were instructed to provide answers to the following prompts: (1) <u>Describe</u> what your engineer(s) is/are doing, (2) Based on the work depicted in your drawing, <u>explain</u> how your engineer(s) is/are using ***Science***, and (3) Based on the work depicted in your drawing, <u>explain</u> how your engineer(s) is/are using ***Mathematics.***

Rubric Development

The DEAMS-R rubric was developed by two science education researchers and one mathematics education researcher in consultation with an engineering researcher. The development of the rubric was informed by literature on the nature of engineering [26], including how science and mathematics knowledge are incorporated within engineering [27], and national reform documents for science [1] and mathematics education [28]. The rubric was reviewed by a panel of experts to establish content validity. To determine reliability, the rubric was used by two science education researchers to independently score 48 DEAMS drawings and prompts.

Description of DEAMS Rubric (DEAMS-R)

The DEAMS-R contains three criteria (Work of an Engineer, Use of Science, Use of Mathematics), each with four progressing performance levels (Unacceptable, Emerging, Acceptable, Target). The levels were developed such that Acceptable included responses that, at a minimum, included all of the information the DEAMS prompts asked for. The descriptor "Target" was chosen because responses at this level represent the level of understanding that should be a target for novice educators to reach. DEAMS-R is used to score the instrument holistically, taking into account the image, speech bubbles, and written response.

Work of an Engineer. An Unacceptable response for this criterion either (a) indicates a mistaken conception of engineers (perhaps a mechanic or construction worker), (b) is vague or unable to be determined, or (c) includes work from a classroom rather than the work of an engineer. An Emerging response includes work that an engineer might engage in (e.g., design or improve things) but there is no context or reference to a problem being addressed. An Acceptable response included both work that an engineer might engage in as well as a context or problem being addressed by the work (i.e., Find a way to make it safe to use a cellphone during flight). A Target response met the Acceptable level and included examples of processes or activities the engineers were engaging in and a basic connection to societal impacts of the work (e.g, health, safety, sustainability).

Use of Science. An Unacceptable response for this criterion either (a) fails to include a response, (b) includes a response that contains no science content or practices, or (c) includes a nonsensical response. An Emerging response includes general science content or practices that are not specific to the work depicted and could be applied to many contexts (i.e. engineer is making observations.). An Acceptable response includes specific science content or practices that directly connect to the work of the depicted engineer (i.e., she works with a lot of chemicals and needs to know the boiling points.). A Target response includes a description of how the depicted engineer is using both science content AND practices that are specific to the work depicted (i.e. They are using the scientific method to test when the small scale bridge will break and what weathering will do to the bridge.).

Use of Mathematics. An Unacceptable response for this criterion either (a) fails to include a response, (b) includes a response that contains no mathematics content or practices, or (c) includes a nonsensical response. An Emerging response includes general mathematics content or practices that are not specific to the work depicted and could be applied to many contexts (i.e.

The engineer is calculating a budget). An Acceptable response includes specific mathematics content or practices that directly connect to the work of the depicted engineer (i.e. calculating the percentage of toxic fumes). A Target response includes specific mathematics content or practices that directly connect to the work of the depicted engineer and a description of the purpose for that mathematics (i.e. calculating speed of car with distance/time to improve their roller coaster).

Results

Content Validity

First, to determine if the developed performance levels captured the range of responses provided by participants, the research team examined the frequency of DEAMS responses that fell within each performance level of each of the three criteria. The frequency distribution in Table 1 indicates DEAMS-R successfully captured a range of participant responses.

Table 1.
Frequency of Participant Responses across Performance Levels

	Unacceptable	Emerging	Acceptable	Target
Work of an Engineer	9	16	18	5
Use of Science	18	11	16	3
Use of Mathematics	15	20	9	4

Second, an expert panel was assembled to provide additional evidence of content (face) validity. Content validity answers the question *does the rubric appear to measure what it aims to measure* and refers specifically to the rubric itself not the scorer using it [29].The expert panel consisted of five members with experience conducting engineering education research and expertise in one of the disciplines assessed by the rubric (two in engineering, two in science, one in mathematics). Panel members were provided with a copy of DEAMS-R, a set of instructions for using DEAMS-R, and a sample of 10 participant drawings and prompt responses. Panelists were asked to provide feedback on the content of DEAMS-R and how well it captured the range of understanding appropriate for the instrument's target audience. Panelist feedback described the appropriateness and adequacy of DEAMS-R. "I think it looks just great and really captures the range of concepts associated with understanding the work of engineers. I do think that you have included the appropriate elements to illustrate the difference between the scale criteria" as well as suggested areas for improvement. The research team carefully considered each piece of feedback and as a result, made several adjustments to refine DEAMS-R. For example, both science education experts expressed concern about the use of NGSS specific language (e.g. science and engineering practices, core ideas) within the rubric as this could limit the scope of use. As a result, the research team adjusted the wording in the rubric to refer to science content and practices using more generalizable language. Additionally, one panelist identified inconsistencies in formatting between some criteria that made the rubric difficult to use. To address this, the research team made adjustments to the format to ensure consistency across both criteria and performance levels.

Reliability

In order to measure the degree of consistency between the two independent raters, both a percent agreement and a weighted Cohen's Kappa were used. Percent agreement among the two raters indicated a good level of agreement with levels of agreement ranging from 81.3% to 83.3% on the three factors. Regardless of the quality of a rubric, researchers [30] have pointed out that it is extremely difficult to get exact consensus between two independent raters. Thus, it is also appropriate to examine the level of adjacent agreement between the two raters which revealed 100% adjacent agreement for Work of an Engineer and Use of Science and a 95.8% agreement for Use of Mathematics. Additionally, a Weighted Kappa was used to measure the level of agreement over and above agreement expected by chance [31]. The Weighted Kappa for agreement between the two raters revealed at a substantial to almost perfect level of agreement [32] for each category: Work of an Engineer ($\kappa_w = .814$, $p < .001$), Use of Science ($\kappa_w = .820$, $p < .001$), and Use of Mathematics ($\kappa_w = .786$, $p < .001$). Additionally, a repeated measures t-test revealed that there was no significant difference ($p < .01$) between reviewers on any of the criteria (Work of an Engineer: $t = -1.000$, $p = .322$; Use of Science: $t = 0.330$, $p = .743$; and Use of Mathematics: $t = -1.071$, $p = .290$).

Conclusions and Implication

The purpose of the current study was to examine the use of the Draw-An-Engineer and Applications of Mathematics and Science (DEAMS) instrument and associated scoring rubric (DEAMS-R) for eliciting elementary teachers' perceptions about the work of engineers and the ways that engineers use mathematics and science. Researchers utilized 48 images from 24 participants to develop and validate a rubric for the DEAMS. A panel of content experts supported its content validity and the reliability of the instrument was established with good percent agreement between raters, high adjacent agreement values, and high Weighted Kappa values. As such, this study provides evidence that the instrument is a valid tool to use in the assessment of adult mental models of the work of an engineer and their perceptions of how an engineer uses mathematics and science in their work.

This study provides evidence that the DEAMS instrument and the DEAMS-R are both reliable and valid to provide educational researchers with a tool to assess elementary educators' conceptions of the work engineers and how engineers utilize mathematics and science in their work. The DEAMS and corresponding DEAMS-R will be a useful tool for teacher educators to assess teachers in preservice and in-service settings (e.g., pre/post assessment of impacts of professional development). Further, they could be used as a self-reflective tool to provide a starting point for educators to engage in discussions around personal conceptions of the work of engineers. Next steps include further examination of participant responses to explore their conceptions of engineers and their use of mathematics and science. This exploration can provide useful information for teacher educators and professional development providers to use when designing engineering- focused instruction for K-12 teachers.

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