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Student Outcomes from the Collective Design and Delivery of Culturally Relevant Engineering Outreach Curricula in Rural and Appalachian Middle Schools*

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Middle school is a pivotal time for career choice, and research is rich with studies on how students perceive engineering, as well as corresponding intervention strategies to introduce younger students to engineering and inform their conceptions of engineering. Unfortunately, such interventions are typically not designed in culturally relevant ways. Consequently, there continues to be a lack of students entering engineering and a low level of diverse candidates for this profession. The purpose of this study was to explore how students in rural and Appalachian Virginia conceive of engineering before and after engagement with culturally relevant hands-on activities in the classroom. We used student responses to the Draw an Engineer Test (DAET), consisting of a drawing and several open-ended prompts administered before and after the set of engagements, to answer our research questions related to changes in students' conceptions of engineering. We used this study to develop recommendations for teachers for the use of such engineering engagement practices and how to best assess their outcomes, including looking at the practicality of the DAET. Overall, we found evidence that our classroom engagements positively influenced students' conceptions of engineering in these settings.

Keywords: middle school; DAET; student conceptions of engineering

1. Introduction

Engineering as a field of study and a career choice is often misunderstood by younger students (e.g., [1]), particularly as influenced by their cultural setting. Yet, middle school is a critical time when students need to begin considering engineering careers to enable optimal academic preparation [2, 3] specifically with regard to the advanced math and science requirements for students' eventual enrollment in college engineering programs [4]. Consequently, there is strong interest in ensuring that middle school students understand the wide array of career opportunities available and what the profession of engineering entails, so they have the opportunity to consider it as a career choice and make relevant and timely academic choices in preparation. Research is rich with studies on how middle school students perceive engineering, as well as corresponding intervention strategies to introduce younger students to engineering and inform their conceptions of engineering (e.g., [3]). Unfortunately, such interventions are typically not designed in culturally relevant ways, often being overly vague or broad [5], and thus the intended message does not reach a broad and diverse audience. As a result, there continues to be a lack of students entering engineering and a low level of diverse candidates available for this profession. Culturally relevant pedagogies are those that "empower students" and include cultural referents to "impart knowledge, skills, and attitudes" [6, p. 20]. Ladson-Billings further asserts that culturally relevant teachings are more than explaining dominant cultures but are part of the curriculum in their own right. She describes teachers who practice culturally relevant methods as those who "believe that all of their students can succeed rather than that failure is inevitable for some. They see themselves as a part of the community and they see teaching as giving back to the community. They help students make connections between their local, national, racial, cultural, and global identities" [6, p. 28]. Though Ladson-Billings often writes of ethnic minorities, her writings also resonate with struggles experienced within the rural and Appalachia Virginia populations and Appalachian culture (e.g., [7, 8]).

Tang and Russ [8] refer to people of Appalachian culture as "an invisible minority because they do not appear outwardly different from mainstream Americans" (p. 34). The Appalachian culture is most notable in Central Appalachia, which includes areas of Eastern Kentucky, Northeast Tennessee, Southern West Virginia, and Southwest Virginia,

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and includes some of the most economically distressed Appalachian counties, lowest levels of postsecondary completion rates, higher unemployment, and higher ratio of manufacturing jobs compared to college-oriented jobs [9]. This region is also connected by a mountainous geography with few to no interstates within the counties, contributing to the microcosm of Appalachia. The culture of Appalachia includes common beliefs of a strong sense of family, remaining local for life, a desire for job security, and issues with trust [8, 10, 11]. In addition, Appalachians continue to have negative cultural assertions (e.g., poverty, dialect, and lesser education) from people within and outside of their culture [8, 10, 12, 13]. Supporting the importance of cultural relevancy, research situated in Appalachia for the purpose of studying Appalachia has shown advantages of using relevant experiences to improve, for instance, scientific literacy or engineering knowledge (e.g., [11, 14, 15]).

Because research shows that conceptions of engineering can originate from home, school, and other personal experiences [16–18], it is important to help students develop overall conceptions of engineering that realistically portray the profession and serve to inspire them. This is especially imperative for students living in rural areas such as the Appalachian and rural southwest regions of Virginia where a lack of seeing and knowing engineers can hamper a student's interest in the field of engineering [11]. For example, a study of the math and science self-efficacy of Central Appalachian students found that despite strong community and family ties, few students had access to social models who are working and studying in math- and science-related fields [19]. Because of the emphasis on local values and community ties for the people of this region, it is important for young people to see engineers and engineering as it happens in their own locality [11].

The purpose of this study was to explore how students in rural and Appalachian Virginia conceived of engineering before and after engagement with culturally relevant hands-on activities in the classroom. Sixth-grade students in three counties participated in a set of engagements intentionally designed to inform them about engineering as it related to the students' own region. These unique and culturally relevant activities were designed collaboratively with members of local industry, classroom teachers, and students and faculty from a local university. Because of this collaborative development, practicality of use by teachers in the classroom was an important factor for both the activities and the evaluations of their effectiveness regarding students' conceptions of engineering.

The following two research questions guided this study:

1. How can multiple instance, culturally relevant engineering-related classroom engagements change sixth-grade students' conceptions of engineering in rural and Appalachian Virginia school systems?
2. What recommendations can be developed for teachers who want to use similar classroom engagements and assessment tools as a measure of how students' conceptions of engineering change over time?

We used student responses to the Draw an Engineer Test (DAET) [20] consisting of a drawing and several open-ended prompts administered before and after the set of engagements to answer these research questions. Note that we have intentionally chosen *activities* or *engagements* rather than *interventions* to describe our interactions with students and consider our series of activities across the school year as an intervention. At the same time, we understand that intervention tends be the term more recognized in the literature and hence some switching between terms is present herein.

2. Literature Review

There is a significant amount of literature that mentions the critical shortage of college graduates nationally in STEM fields, including engineering [21] but also specifically in Virginia (e.g., [22]). In order to meet demands for more engineers, interest in engineering needs to be captured at a young age, such as in middle school, because of the academic and process preparedness required [23]. However, it is difficult for a young person to aspire to become a certain type of professional, such as an engineer, without understanding the profession itself [24], being academically prepared [23], and having an interest that is not only sparked but sustained [18]. If awareness, preparation, and interest are not established in a timely manner, potentially strong engineering candidates will be lost. By focusing on informing the conception of engineering held by young students, such as those living in rural and less affluent areas where attending college does not receive the same attention as urban or affluent areas, the available population of engineering candidates could potentially be expanded using customized intervention strategies. At the same time, to understand if such interventions are making a difference, we must have an age-appropriate and robust measure of students' conceptions of engineering. To ground our study, we provide an overview of the ample literature that describes middle school students' conceptions of engineering, examples of what has been learned from prior intervention studies, and different ways conceptions of engineering among young people can be measured.

2.1 Middle School Students Conceptions of Engineering

Broadly, research on middle school students' conceptions of engineering shows commonalities across studies. For example, recent studies have shown that K-12 students often represent engineers as people who: build, test, fix, and repair products (e.g., vehicles and structures) [16, 17, 25]; study, make, or improve things [16]; and work on or invent things [17]. Researchers also examine characteristics of engineers, sometimes in comparison to scientists, as a way to conceptualize engineering. For example, one study found that students described engineers as being good at math, doing boring things, and making people's lives easier while describing scientists as being creative, using their brains, doing many kinds of work with various forms of communication, agreeing on the best way to solve problems, and being more likely to discover new knowledge [26]. Some characteristics of engineering work, such as the notion of engineers as being good at math and science, have endured as messaging young people receive from adults [27]. More recently, the messaging focus has been on engineering as design work [28].

What is missing from the current literature is a solid understanding of the differences in conceptions of engineering held by young people from different backgrounds, how such conceptions are formed, and how they function for students in the shaping of future career choices. The literature is not void in this area, but it is incomplete. For example, Capobianco, Diefes-Dux, Mena, and Weller [29] showed differences between urban and suburban youth's conceptions of engineering with "laborer" being a more common conception among students from urban schools and "technician" more common among students from suburban schools. However, the evolution or function of these conceptions was not addressed. Matusovich, Gillen, Carrico, Knight, and Grohs [30] began filling this gap by demonstrating connections between outcome expectations for high school students associated with engineering careers to those held by school counselors, teachers, and principals based on the kind of engineering work that is prevalent in the region surrounding the high school. Additional similar research will be needed to fully understand differences in conceptions of engineering between young people from different demographic groups.

2.2 Interventions Work to Change Conceptions of Engineering

Many interventions exist to help young people conceptualize engineering. We will not review them all here, but rather we will focus on a few that are most similar to our goal of supporting culturally relevant conceptions of engineering. For instance, Hammack and High [31] explored the impact of a structured after-school mentoring program on the conceptions of engineers held by middle school girls. The girls met weekly with their college student mentors, which included time for relationship building, engaging in practical engineering projects such as water purification, and time to talk about engineering careers. Based on results from pre-post DAET implementations, the authors found a shift from students viewing engineers as laborers who build and fix things to "more creative individuals who design and innovate to solve problems to improve the world and help people" (p. 15). Based on the goal of their project, they report this as an important, positive change. Mentorship by college engineering students was central to their intervention and, as indicated by their implications, a contributor to the success of the program, even though they could not explicate the direct impact. Our project is similar in that we intentionally partnered middle school teachers, university representatives (including engineering students), and industry partners in extended engagements in the classroom with students.

Our work is also similar to that of Colvin, Lyden, and León de la Barra [32] who engaged with middle school students in Australia, particularly around civil engineering. The project team designed several lessons related to civil engineering that were specifically tied to Australian Science standards. They focused the messaging of the modules on the idea that civil engineering ties directly with communal goals and values. Also, using a DAET as a pre and post measure, they found evidence of increased representation of civil engineers in the post-test and a slight increase in the representation of communal goals in the post-test. Such results suggest promise for our program.

Again, these two programs, which are just a sampling of the existing interventions, support the notion that interventions can effectively change students' conceptions of engineering. Where our program differs from both of these examples and other existing programs, is in the collaborative development of the classroom activities and the incorporation of local industry partners. Both of these elements are intended to integrate relevant local context more fully into the classroom engagements.

2.3 Measuring Students' Conceptions of Engineering

While students' conceptions of engineering are important to understand, measuring these conceptions is challenging because it can be difficult for young students to put their perceptions of engineering into words. The DAET, utilizing a drawing exercise, has been widely used to evaluate the effectiveness of engineering-related programming for middle grade students in US and international contexts. For example, the DAET has been used in suburban [31] and rural [33] contexts, as well as across other demographics such as single gender [34] and single race [35] studies. The DAET is often used alongside other methods, for example, the Middle School Students Attitude to Science, Math and Engineering Survey (MATE) [34], and with single race students [17]. There is evidence that quantitative surveys like MATE alone do not provide enough detail about younger students' conceptions of engineering, suggesting the usefulness of additional qualitative tools like the DAET to enrich the findings [34]. Notably, in most of these applications, the DAET is part of a research project and the research team is conducting the data collection and analysis. Few critiques of the DAET as a tool exist beyond the labor-intensive nature of the analysis.

3. Classroom Engagement Description

We designed our classroom engagements as activities with a strong hands-on component to support a particular Commonwealth of Virginia standard of learning (SOL). Each activity was designed to last an entire class period (60 minutes or 90 minutes depending on the school's schedule). In planning the activities, we considered (1) the SOLs, (2) cultural relevance, (3) relationship to the industry partners, and (4) specific engineering connections. Early in the first year, we added graduate students studying in STEM fields to the above considerations which provided young students with an opportunity to meet STEM college students of different races, ethnicities, and genders [36]. After describing our general philosophy of and process for activity design, we will provide a specific example.

3.1 General Philosophy of and Process for Designing Activities

Our NSF-funded project, PEERS (Partnering with Educators and Engineers in Rural Schools), focuses on the collaborative design, implementation, and study of recurrent hands-on engineering activities with middle school youth. To achieve this aim, the team partners with school educators and industry experts in students' local communities to collectively develop curriculum to meet teacher-identified science standards and to facilitate regular in-class interventions throughout the academic year. These in-class interventions are led by the collaborative team so that teachers, industry volunteers, and university affiliates are collectively working with youth. We believe that successful programs must holistically integrate these interested sectors. PEERS focuses on building cross-sector partnerships with school educators and industry experts local to each of the three target rural communities (local cultural context) to regularly integrate locally relevant hands-on engineering activities with the core science curriculum. To intentionally connect with engineering career development activities, industry partners periodically discuss needs in their own companies for employees from varied educational backgrounds and how intervention activities align with content or skills needed to be successful in their industry [36]. These priorities are primarily funneled through university affiliates in curriculum planning but also occur ad hoc in the classroom when industry shares their insights with the students during activity introductions or wrap-ups. While collaborative planning, curriculum development, and professional skill-building is ongoing throughout the academic year, PEERS also hosts an annual summit each summer which brings together teachers, industry representatives, and university affiliates to build trust, reflect on prior work, set goals for the upcoming year, and create opportunities for focused design and development.

3.1.1 The SOLs

Throughout the first year, a common focus of the academic year on scientific method emerged. This is an overarching Virginia SOL for sixth grade and is closely aligned with engineering work under the Next Generation Science Standards [37]. Within this focus, we developed eight topical lessons in partnership with classroom teachers and industry partners addressing culturally relevant topics such as the engineering design and repair of flashlights, design and building of mountain roads, the importance of ecosystem interaction in community design, and water filtration design and testing. The major curricular elements in each of these classroom engagements aligned with existing learning standards emphasizing hands-on classroom activities, forging connections to engineering thinking and engineering careers, and creating relevancy for rural and Appalachian youth. Evaluation criteria used to design and assess the efficacy of the lesson designs were adapted from Cunningham and Lachapelle [38].

3.1.2 Being Culturally Relevant

PEERS strives to build collective capacity within schools and with regional industry partners to sustainably invest in the lives and futures of youth in the region. The challenges facing rural school systems are often interwoven with other critical societal issues. While the day-to-day activity of PEERS is the collaborative design and implementation of engineering activities to foster student interest in STEM careers, the intentional work to develop partnerships with and between schools and industry looks to build sustainability beyond the NSF grant and speaks to a deeper and broader investment in collaborating to improve the quality of education in the region.

Within each engagement activity, we purposely asked ourselves how we could make it relevant to our rural schools, and how would the type of product and/or types of technical jobs at our industry partners tie in. During the activities, we asked our industry partners to give an example of how the activity connected to their work. For example, one industry partner takes advantage of gravity in the design of their process line to save energy and discussed potential versus kinetic energy. Another tie in was to our waste water activity and our industry partners' environmental engineering efforts to reduce waste, especially waste that has the potential to contaminate local water ways (including via warming).

3.1.3 Our Local Industry Partners

Our local industry partners were invited to support the classroom activities through direct hands-on engagement as well as through reviewing, editing, and even developing some lessons. Most of the volunteers in the classroom were professional engineers, a few were scientists, and, on occasion, some were production managers and technicians. All could speak to the engineering activities and focus at their facilities and were asked regularly to make connections between the activities students were doing and "real life" work in their facilities. Through regular engagement in classrooms, the industry representatives served as examples of the types of careers existing in students' home communities and the diversity of skill sets associated with the field of engineering. Importantly, working with every student via all sixth grade science teachers during the school day ensured socio-economic barriers (e.g., after-school transportation) or academic-tracking (e.g., innovative projects deployed in "gifted programs" only) did not limit participation and the benefits of interaction with local industry partners.

3.1.4 Intentional Connections to Engineering

Initially, our team anticipated that our local industry partners would provide the local engineering context and career connections to lessons in the classroom. While this did happen anecdotally, scaffolding for these inputs was created over time. The PEERS implementation team provided scripting for industry partners to help guide connections between local engineering practices and the targeted science lesson. Additionally, graduate student volunteers offered connections between the lesson content and their fields of engineering study and practice to broaden the relevance and career connections for students and teachers. All lessons were grounded in an engineering design process context that allowed and encouraged students to "practice engineering" during the lesson as they assessed problems, explored solutions, created prototypes, and tested solutions.

At the beginning of each lesson, we asked students to tell us what they knew about engineering generally and/or if they knew any engineers in their family or community. Answers varied and often even led to questions such as, "My dad is a mechanic, is that engineering?" To which we would reply, yes, there are engineering elements to the job of a mechanic. After initial brainstorming, we would ask students if engineers would be involved in the design, repair, or building of whatever the lesson entailed at the time (e.g., Do you think engineers helped design and build flashlights? What parts of a flashlight do you believe an engineer might have helped design, build, or improve?) Our guidance was around general elements of engineering, yet often the activities we created were about troubleshooting and fixing items or models.

3.2 Example Activity

Selected lessons were delivered monthly to all sixth graders in our study which included every section of the science course within each of our engaged schools, for a total of 757 students across 45 days in 182 class periods during the 2017–18 academic year. While not all classrooms performed all activities (Table 1), each activity that they engaged in involved local industry partners who provided local context, engineering expertise, and hands-on support in the classrooms. Additionally, university students pursuing STEM degrees (e.g., biological systems engineering, aerospace, and computer programming) provided in-class support and curriculum development. These degree-seeking students offered a unique perspective as they modeled academic and career opportunities in engineering to the sixth graders.

3.3 Detailed Activity Design Example

The first activity in each classroom was linked to the learning objectives of reasoning and logic (Virginia SOL 6.1). In this activity, students examined a

Table 1. Lessons completed per county

Lesson Topic	Springfield County	New County	South County
Scientific Method	X	X	X
Osmosis and Diffusion	X		
Ecosystem Interaction	X		
Scientific Method Revisited	X	X	X
Water Filtration	X	X	X
Potential and Kinetic Energy		X	
Earth and Space		X	X
Periodic Table		X	X

common tool found in most households – a flashlight. They identified independent variables as elements that could be broken (e.g., burnt bulb, missing batteries, broken connection) and the dependent variable related to its functionality (i.e., the flashlight lights or does not light). When provided with a broken flashlight, students then generated a hypothesis about why it was broken and tested their predictions. Aspects of this conversation highlighted the cultural relevance through the examples given by students such as needing a working flashlight for early morning hunting, a response that would not likely be common in an urban setting. This lesson offered a typical household item (i.e., flashlight) and invited investigation of that item through exploration and collaboration to find a solution. In many cases, students brought various skills and experiences not regularly associated with academic success to this lesson experience (e.g., tinkering, home repair material knowledge, and risk taking – things might get more broken before fixed). Another activity involved exploring potential and kinetic energy by designing and building mountain roads out of simple hardware store materials and using marbles as "cars" to test the roads. Similar to the flashlight activity, this activity reinforced the local relevancy emphasis in the lesson design, as students made connections between the roads they built in the classroom and the challenges resulting from the geography of their local mountainous, rural area. In both cases, industry partners offered insights from their technical science/engineering backgrounds and related company practices while assisting with the hands-on activities in the classroom. For example, one industry partner relayed how they "took advantage" of potential energy by designing process lines that traveled between the first and second levels of their building to minimize their energy costs and take advantage of material drying times while their product moved throughout the facility. Similarly, several industry partners related the process of fixing flashlights to the work done by their maintenance teams, engineers and technicians who were responsible for trouble shooting equipment, and how important it is to keep equipment running and to know how things work.

4. Methods

The overall study design included a series of classroom engagement activities with a pre-measure of students' conceptions of engineering at the start of the academic year and a post-measure at the end. All students present participated in the classroom engagement activities and completed pre- and post-measures. However, formal analysis included only data from students with completed consent/assent forms. Because we had a large sample size and relatively short responses, we quantitized [39, 40] our qualitative results by coding and counting student responses. Methodologically, the approach used herein is still considered a qualitative analysis versus a mixed methods or quantitative approach. This approach is similar to the approach taken by others such as Hammack and High [31]. Our study was conducted in accordance with a university-approved protocol for human subject research.

4.1 Sample Population

In framing their study of school-community partnerships in Virginia, Alleman and Holly identified that young rural Virginians face issues of poverty, lower levels of education, lower eventual salaries, and higher drop-out rates [41]. Our sample population, consisting of rural middle school science classroom students in seven schools in three counties within or near the rural and Appalachian region of Virginia, face similar systemic challenges. Table 2 presents U.S. Census [42] data for each of the school counties. The information is presented in ranges to further protect our participants' identities. Notably, two counties fall below the median household income for the whole nation and all counties fall below the national figures for degree holders. Eligibility for free and reduced lunch can be used as an indicator of relative socioeconomic status and some individual schools may be as high as 70% of all students according to school administration.

Table 2. Descriptive data for the county level from U.S. Census [42] for each case site

County	Population	Median household income	Bachelor's degree or higher	K-12 students eligible for free and reduced lunch
South County	30,000 – 39,999	$30,000 – $39,999	10% – 19%	50% – 59%
Springfield County	70,000 – 79,999	$50,000 – $59,999	20% – 29%	30% – 39%
New County	10,000 – 19,999	$40,000 – $49,999	10% – 19%	40% – 49%

Table 3. Codes and their definition that are related to verbs associated to what engineers do

Code	Definition
Fix	Specific mention of fixing or repairing, more specific than the general phrase "works on"
Build	Specific mention of build or construct
Help/Improve/Make Better	Specific use of these, or related words, with the idea of making things better for people or the community
Design	Specific use of the word design
Make/Create/Invent	Specific use of these words with the idea of making something new
Works on	A general phrase less specific than fixing, building, designing, etc.
Use Math or Science	Direct use of these words
Solve Problems	Direct or implied use of these words
Other	A category to capture other phrases

Within this research study, lesson plans were collaboratively implemented in a total of 182 class sessions throughout the year involving 757 sixth-grade students. Of those 757 students, up to 95 participated in two classroom activities, 246 participated in three classroom activities and 316 participated in all six. These numbers represent every student enrolled in sixth grade science at these seven schools, though not all may have been present for all activities.

4.2 Data Collection Instruments

At the start of the first classroom engagement activity, students completed a pre-test that included two sets of questions followed by a prompted drawing [20]. The questions were: (1) What does an engineer do? and (2) Do you know any engineers? Who are they? Then students were prompted to draw a picture of an engineer at work. The questions and drawing were completed on a single sheet of paper provided to students. Since students typically sat at tables, they were also given colored pens or pencils to share at each table to complete the pre-test. Approximately 15 minutes was allotted for the students to complete the pre-test.

Given the size and scope of our project, we intentionally bounded the scope of the data collection instrument. Whereas other researchers have used short interviews with all participants or a sample of participants [29] or complex coding schemes on the drawings only [43], we used our two sets of questions for the pre-test to provide some context for the students' DAET results. After the final classroom engagement activity, students were asked to complete an identical post-test including the same two sets of questions and DAET. Pre- and post-intervention data were analyzed in the same ways and the results were compared.

4.3 Data Analysis

The two sets of questions on knowing an engineer and describing what engineers do were analyzed by examining student responses and applying frequency coding [44]. The question on knowing an engineer was written in a binary format and answers were "Yes", "No". Therefore, we used a direct comparison of answers, i.e., yes/no responses for each student for the pre- and post-tests. We further reviewed the responses that changed to "Yes" to see who participants identified (family/friends or project team members) as the engineer they know. For the question on what an engineer does, we created categories for coding, and later counting, that were informed by prior literature (as summarized in the literature review). The codes and definitions are included in Table 3. Many responses were tagged with multiple codes as shown in Table 4. Data was initially coded by the third author and then re-examined by the first author. The first and second author engaged in a cycle of checking for interrater agreement where they coded independently and then compared and discussed results until agreement was reached.

To analyze the students' DAET drawings, we used descriptive coding [44–46]. Following the approach used by Knight and Cunningham [20] and Capobianco, Diefes-Dux, Mena, and Weller [29], we divided codes into two categories: (a) *verbs* such fixing, building, or helping, and (b) *objects* such as tools, vehicles, and buildings. Because of the high prevalence of drawings of mechanics, we added this as a category. We translated the drawings, i.e., we examined them and described what was

Table 4. Examples of coded excerpts for the question on what engineers do

Response	Coding
They fix and create things that help people	Fix Make/Create/Invent Help/Improve/Make Better
They build electronics, furniture, and everything around us	Build (note not Help since there is no indication of improving or making things better)
They work in groups and solve problems	Other (for work in groups) Solve Problems
They work in groups and work on cars and stuff	Other (for work in groups) Work on
An engineer uses science, math, technology to make and design things	Math/Science Design Make/Create/Invent

depicted, such that we could apply the codes. For example, *fixing* indicated a broken object the engineer was working on, *building* indicated the construction of an object, and *designing* was used if the engineer was labeled by the student or appeared to be creating something original, often on a computer or paper. The complete list of codes and definitions is included in Table 5. Note that mechanic is the unique descriptor as it is a person working on a specific product in a specific way (a person *fixing* a *vehicle* as opposed to a person *designing* a *vehicle*). The third author conducted the primary coding of the drawings in consultation with the first author and through discussion with the whole project team. Again, during analysis, we quantitized the results by counting the number of representations in each category and comparing pre– and post-intervention results.

4.4 Limitations

Limitations of this study stem primarily from a combination of challenges related to collecting data in a school setting and limitations of our instrumentation. With regard to the school setting, getting consent forms to and from teachers who were getting them to and from parents/guardians was challenging and resulted in lower consent rates than we would have liked. Because of individual school requirements, we had some differences in the number of interventions completed within each classroom. With regard to instrumentation, while the intention was to measure student conceptions around engineering, drawing and writing skill levels may have been a barrier resulting in data that, while still useful for interpreting overarching trends, was less rich than anticipated. These factors were amplified by the limited time that was available during the class period to complete the questions and the DAET. Despite this shortcoming, because of the large amount of data and corroborating evidence, we were able to draw conclusions about student conceptions. Finally, we did not ask participants to identify personal demographics on their forms, so we were not able to draw comparative conclusions based on variables such as race, ethnicity, gender or sex. Note that in 2017 in Central Appalachia, 95% of the population was white alone, not Hispanic, which was a one percent decrease from 2010. For the Appalachian region of Virginia, 89% of the population was white alone, not Hispanic, in 2017, which was a 1.4% decrease from 2010 [9]. Though the demographics from class to class may

Table 5. Codes used for the DAET

Verbs	Definition	Nouns	Definition
Building	If the figure was constructing something, often a building (noun)	Vehicle	If a car or truck was drawn
Serving	If a figure was labeled as "helping" or "serving" or if the figure was speaking to another figure, asking for help	Workbench	If a bench or table was a part of the drawing, either being worked on or as a place holding tools, blueprints, etc.
Designing	If the figure was labeled as "designing" or appeared to be creating something original, often on a computer or a paper	Computer	If a computer was being used or made by the figure or if a computer was drawn
Making	If the figure was labeled as "making" or assembling something	Tool	If the figure was holding or using a tool or if a tools were spotted in the drawing
Fixing	If the figure was labeled to be fixing something, in the act of fixing something that was drawn or labeled as "broken"	Blueprint	Any drawing on a paper or computer screen that indicated it was a design of something
Mining	If the figure was either in the act of mining or in a mine	Electronics	If any electronics were labeled or drawn. These may be used by the figure or being created by the figure (e.g., iPhone)
Welding	If the figure was in the process of welding or was holding welding uniform (mask and blow torch)	Building	If a build was drawn (e.g., house, office, etc.)
		Train	If a train was labeled or drawn in the picture
		Mechanic	If the drawing showed specific tools, a workshop, auto lift, or any other indication that the student was drawing a person whose job was as a mechanic

have varied, we have no reason to believe the participants' demographics varied from these data.

5. Results

Using a form of the DAET, we measured students' conceptions of engineering in three ways: asking if they know engineers, asking what engineers do, and asking them to draw an engineer at work. We measured these conceptions before and after a series of classroom interventions. In comparing our pre- and post-results, we found evidence that our intervention positively influenced students' conceptions of engineering. We consider positive to be changes that are consistent with our intention of broadening students' conceptions of engineering, such as being able to identify people they know that may be engineers or shifts to concrete and functional definitions of engineering. In that regard, we have two specific findings. First, we found an increase in the number of students indicating that they know an engineer, with several noting members of the project team and others indicating people doing engineering work associated with our intervention activities. Second, we found shifts in nouns and verbs associated with describing engineering work. Verbs shifted from the abstract and popular messaging, i.e., *designing*, to more concrete or actionable terms such as *fixing* or *building* that were represented in our interventions. The use of nouns shifted to represent objects associated with the activities we had designed to be culturally relevant.

5.1 Do you know any Engineers?

Being able to identify people that work as engineers is a way to view how students conceive of engineering. In response to the pre- and post-questions on knowing an engineer, we saw a shift as summarized in Table 6. The data confirm that few students indicate knowing engineers in our regions of study; the sample started with more negative than affirmative responses and even though some students switched to affirmative responses after the interventions, the total of negative responses at the end of our study still exceeded the number of positive responses.

In examining the 43 responses that changed from *No* to *Yes*, we found that 32 students indicated a family member or friend, 10 indicated a member of the project team, and 1 response did not indicate relationship. Occasionally, but not always, students offered context if they responded *Yes* and listed a person. For example, a person who remained a *Yes* response wrote a version of: "My mom builds trucks at [local industry]" for the pre and post responses. Given the limited context provided with the responses, we cannot externally evaluate if the listed individuals are actually degreed or titled engineers. Importantly, the changes to *Yes* suggest connections to our classroom engagements. For example, one participant who changed from *No* to *Yes* wrote: "I think my Dad is one. He works for VDOT". VDOT is the Virginia Department of Transportation so it is possible that the student indicated this based on the mountain roads activity where we talked about some engineering work/ activities associated with designing and building mountain roads, such as the students would regularly travel on in this region. Another participant who changed to *Yes*, wrote, "My dad builds houses" which may be associated with our biome activity where students added buildings to a landscape to consider impacts of weather. Changes from *Yes* to *No* were often a family member that was listed initially but not listed at the end. Overall, more participants identified men than women as engineers they know which is not remarkable since there are more men actually working as engineers [47].

5.2 What does an Engineer do?

Identifying the work engineers do also offers insights into conceptions of engineering. In examining the response to the question about what an engineer does, the data revealed an increase in frequency of responses coded as having the root terms of "fix," "build," and "works on" with a decrease in frequency of the root terms "create," "help," and "design," when comparing pre and post classroom engagement responses (Fig. 1). Although low to start with, responses about using math and science and solving problems declined further on the post-test. Answers to this question were very short and on the order of one partial sentence, so again, context was limited. Moreover, answers were not always articulate with regard to the object(s) engineers "create", "build," or "design" using words like "things" and "stuff." Given the age of students, the specific prompt

Table 6. Change of response to the pre- and post-question on whether the participants knew an engineer

Yes	**# Responses**	**No**	**# Responses**
Stay Yes	65	Stay No	99
Change to Yes	43	Change to No	25
Total Yes (Post)	108	Total No (Post)	124

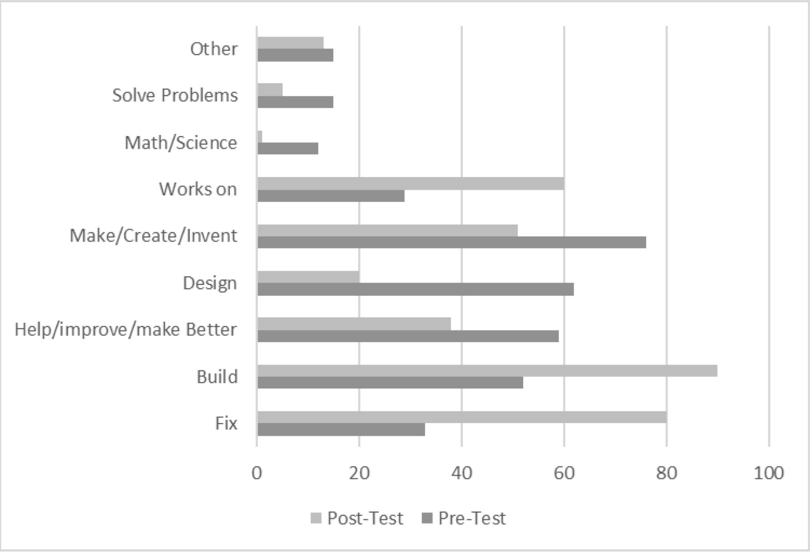

Fig. 1. Responses to open-ended question on what engineers do.

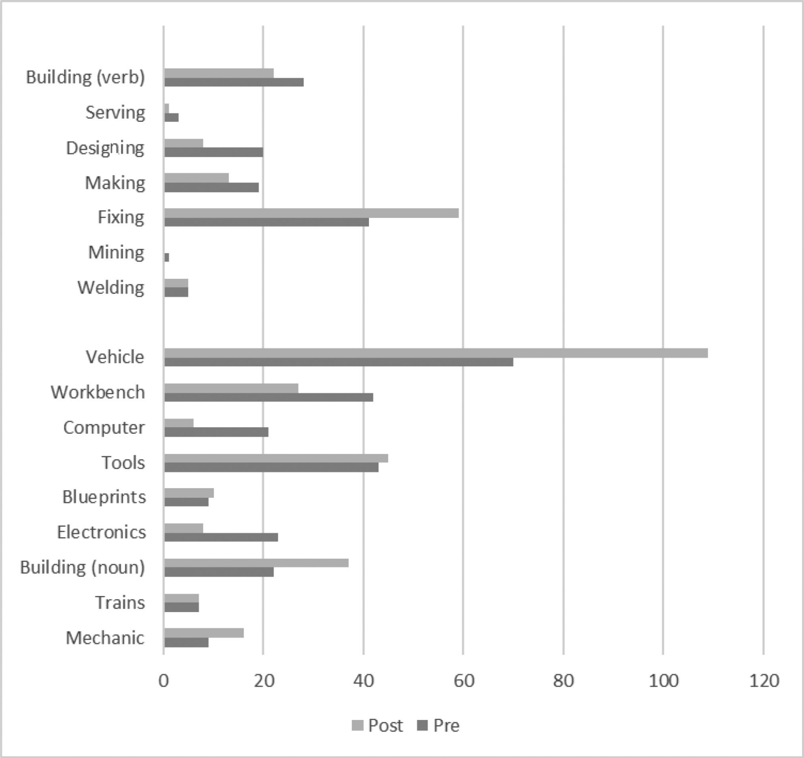

Fig. 2. Nouns and verbs associated with the DAET.

related to what the engineer is doing, and the time limitation, it is not surprising that less articulation happened around the objects associated with doing engineering.

5.3 Draw an Engineer at Work

Asking students to draw an engineer at work provides a visual representation of conceptions of engineering work. Results from the drawing analysis generally echo the analysis of the open-ended responses to the question about what engineers do, but the drawings add some nuance, particularly with regard to objects. Because the drawings often included a specific object on which the engineer was working, we were able to code for what activity was being done (verb) and on what (object) as performed by Capobianco, Diefes-Dux, Mena, and Weller [29] and Knight and Cunningham [20]

(Figure 2). The analysis of verbs showed a relative decrease in "designing" and increase in "fixing". Regarding nouns depicted in the drawings, we saw an increase in "buildings" and "vehicle" with a relative decrease in the depictions with a "workbench" and "computer". As described earlier, mountain roads (which led to some discussion of cars) and buildings were prominent in our classroom engagement activities. One industry partner specifically talked about products they manufacture that go into cars. A decrease in mentions of computers may be attributable to the idea that our lessons did not involve the use of computers but tended to be hands-on and associated with non-computer oriented physical environs like mountain roads, biomes, and bees.

6. Discussion

There is still much we can learn from middle school students about how to best introduce them to the wonders of the field of engineering. By taking into consideration the local culture in which middle school students are immersed, there is an opportunity to better relate to them what engineering is about and what their many options are for careers in engineering. Middle school students benefit from information that is presented in a culturally relevant manner so students can "see" the relationship engineering has to the cultural setting in which they live, and thus, its connections to them on an individual level. Our study aimed to find effective ways to accomplish this mission of sharing information with middle school students in a meaningful way to broaden their conceptions of and spark their interest in engineering and support a realization that a career in engineering is attainable for them, no matter where they live.

6.1 Changing Conceptions of Engineering

In response to our first research question regarding students' conceptions of engineering, we believe that as measured with the DAET, a multiple instance, culturally relevant engineering-related classroom engagement can change sixth-grade students' conceptions of engineering in rural and Appalachian Virginia school systems. However, we recognize that we cannot explicitly determine the degree of change or unquestioningly confirm the specific causes as related to our classroom engagements. At the same time, the volume of data and nature of changes suggest a shift to thinking about engineering in ways that are consistent with how the students might be seeing engineering in their local environment.

Our findings are similar to those in prior studies with regard to the types of nouns and verbs students associate with engineering (fixing, building, etc. as noted in the introduction) but the key to our findings is the shift in the types of nouns and verbs used by the sixth-grade students over time. As noted in the descriptions of our learning activities, we intentionally talked to students about engineering as fixing, building, and as design. The fixing and building were part of conversations that related learning activities to the local culture as in our flashlight activity and the example of hunting provided by a student. In our sample, the shift to seeing fixing and building as engineering work after the classroom activities is relevant to our participants who live in lower SES, rural areas. Research does show that different regions, urban and suburban, can have similarities and differences in conceptions of engineering with laborer being a more common conception among students from urban schools and technician from suburban schools [29]. At the same time, the idea of fixing and repairing is resonate with even high school students noting beliefs that engineering is maintenance-related [48].

Although not perceived by some as an appropriate definition of engineering (e.g., [28]), "fixing" may in fact be a relevant way for rural students to think about the possibility of engineering (as an entry point). A broader trend in the literature suggests that a shift in younger students' comparisons away from the physical aspects of engineering (e.g., building, fixing, constructing) or towards more technical language about sub-fields [17] and cognitive tasks like designing and experimenting [31, 35] is positive. However, because engineering is broader than designing and experimenting and does include aspects of fixing/repairing, for example at some manufacturing facilities, fixing/repairing may be a relatable connection to engineering work for students, such as those living in rural and Appalachian regions. Recent research within engineering education has focused on a need to consider other ways of knowing and being relative to engineering, i.e., funds of knowledge [49] as critical to broadening participation in engineering.

6.1.1 The Importance of Age-appropriate Activities to Changing Students' Conception of Engineering

We might also argue that verbs like fixing and building that were more commonly associated with the post-test may be more developmentally appropriate for middle school students than designing and creating. The students in this study are sixth-grade students, typically ages 11 to 12 of all ability levels. If we follow Piaget's theory of cognitive development [50], this critical age is considered a cognitive tipping point from concrete to the abstract thought. Children learn a new concept in the concrete form before being able to understand or describe a more abstract understanding of it [51]. This type of concrete thinking often stems from ideas and concepts that they already know, what they can see, and what they can manipulate, allowing the student to develop a relational connection to it [52]. This *concrete operational stage* is one that typically begins around the ages of 6 or 7 and lasts through 11 or 12. It is signified by children applying new knowledge to concrete, observable objects and events [53]. The prohibitive barrier to this development stage is the inability to think beyond what is observable and relational to them, which increases the importance of helping middle school students "see" the engineering happening around them.

When children mature into early adolescence, they can then start to reason into abstract concepts and hypothetical ideas. This phase is called the *formal operational stage*. The formal operational stage is described as beginning in early adolescence and into adulthood, typically around the ages of 11 or 12. During this period students begin to formulate questions and develop tactics and trials to seek answers to those questions [53, 54]. They are able to think about situations that have no basis in the concrete reality and can make decisions in the abstract [53, 55]. In other words, their thought processes develop the mature ability to move into the abstract realm which includes designing and creating. As mentioned before, the students in this study are at a cognitive transition where they may or may not have matured from concrete to abstract thinking, or the concrete operational phase to the formal operational phase. They are ages 11–12 and are still learning how to apply what they concretely know through their senses and experiences to hypothetical situations and reasoning. The concepts of "fixing," "building," or "making" are concrete actions that students feel comfortable using to describe the definitions and have past experience or connections to. The ideas of "creating" or "designing" are a more abstract facet of the engineering definition, requiring the student to see beyond what they have in front of them and are asked to do and apply beyond the familiarity and into the hypothetical or abstract realms. Engineering is a multi-faceted concept for students to develop, consisting of not just the physical act of building and making (for example), but the abstract thought process of "designing" and "creating." Therefore, these students may not have "lost" the idea of designing and creating as the frequency data may indicate, but may have gained a fundamental understanding of engineering at the concrete conceptual level, that can then be reinforced and enhanced to transcend into the abstract conceptual level of "designing" and "creating." This offers students an understandable window into the whole world of what engineering "is" and what engineers "do."

6.2 Recommendations for Teachers Regarding Use of the DAET to Measure Students Conceptions of Engineering

Regarding our second research question about recommendations for teachers, we have several pragmatic recommendations. Although the DAET may be appealing because it does not resemble a traditional test, the DAET is time intensive to administer, labor intensive to code, and in summary not recommended for teachers based on our experience. Regarding administration, if students are not given sufficient time to make their drawings, the drawings are incomplete and difficult to interpret. Many administrations of the DAET include interviews to assist in interpretation of the drawings [29], requiring even more time. Taking class time to make such drawings and interviews is a challenge in already packed schedules, even with researchers from outside the classroom delivering the lessons and gathering the data. This would be nearly impossible for teachers themselves to perform with limited class time. With regard to analysis, coding of the drawings is even more labor intensive than the administration of the DAET. In 2011, Dyehouse, Weber, Kharchenko, Duncan, Strobel, and Diefes-Dux [43] attempted to eliminate the interviews and proposed a coding approach to account for the lack of interpretation data from the interviews. This process requires six rounds of coding with inter-rater checks. Such an approach is simply not feasible for teachers. If we want teachers to engage in teaching engineering, we need a user-friendly action research method for them to assess if interventions are making a difference in students' conception of engineering. Furthermore, recent research challenges the basic function of the Draw-A-Scientist Test (the foundation upon which the DAET was built), showing that even adults had trouble with drawing for such a test [56].

A variety of potentially less cumbersome methods exist to quickly evaluate classroom engagements with regard to their efficacy to promote positive changes in students' conceptions of engineering. While many of such methods are still aimed towards research uses, teachers could use these tools or even parts of them to look for before and after change. For example, Blanchard, Judy, Muller, Crawford, Petrosino, White, Lin, and Wood [57] created a survey from existing instruments and a few original questions to examine the benefits of an engagement with students. The survey includes questions on engineering interests, knowledge, and plans. To offer some explanatory power, the authors also used focus groups to understand student experiences. While everyday classroom conversations can also serve as focus groups in some capacity, teachers may wish to have a more formal way to document such experiences. Therefore, an approach used by Lee and Lutz [58] where closed-ended survey questions were used to anchor open-ended response might be helpful. In such an approach, teachers might choose a few salient questions from an existing survey (or create their own) that could be rated on a scale. They could then ask a related open-ended question that elicits deeper understanding. For example, a question that asks for degree of agreement with the statement, "Engineers solve problems", could be supplemented with a question that asks for an example of a problem they might solve. The teacher could then examine responses quickly for examples that might be associated with the classroom engagement. These methods, as a form of student reflection, may further provide a means for teachers to assess student learning from the activities resulting in less added time required.

7. Conclusions and Future Work

There exists a critical need to help middle school students understand engineering in order to expand the pool of potential engineers, both by number and diversity. Interventions have been used in practice to inform pre-college students about engineering, but these interventions were largely not designed to be culturally relevant. Our study showed that a series of culturally relevant classroom engagements used to explore engineering with rural and Appalachian sixth graders was effective in changing their conceptions about engineering. In the case of explaining the field of engineering and helping young students to visualize it, it is beneficial to "bring it home" for the young student, wherever that local home might be. The collaboration between local industry and school systems in the design and delivery of interventions enhances their cultural relevancy for local students.

Future studies could include the preparation of guidelines for how to design a culturally relevant intervention to inform local students about engineering or conducting a similar study in a different setting, such as urban. To compliment this study, researchers could look at Appalachian parents of middle schoolers' conceptions of what an engineer does. A literature review of culturally relevant interventions for K-12 students would also be useful. Finally, a study could be conducted to design a more user-friendly method for teachers to assess engineering interventions.

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