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Evaluating Fourth-Grader's Perception of Engineering Through a Community-Engaged Project (Evaluation)

Olivia Ryan, Virginia Polytechnic Institute and State University

Olivia Ryan is a Ph.D. student in Engineering Education and a Master's student in Engineering Mechanics at Virginia Tech. She holds a B.S. in engineering with a specialization in electrical engineering from Roger Williams University. Her research interests include developing professional skills for engineering students and understanding curriculum barriers that exist within engineering related to mathematics.

Dr. Maija A Benitz, Roger Williams University

Dr. Maija Benitz is an Associate Professor of Engineering at Roger Williams University, where she has taught since 2017. Prior to joining RWU, she taught at the Evergreen State College in Olympia, WA, after completing her doctoral work jointly in the Multiphase Flow Laboratory and the Wind Energy Center at UMass Amherst.

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Abstract

To meet the complex challenges of the future, there needs to be an increase in the number of students pursuing STEM and engineering. To grow those numbers, students must have an understanding and interest in engineering in order to pursue it as a career option. However, literature has shown that children hold misconceptions about the engineering profession, which can deter potential future engineers from the field. This underscores the importance of introducing engineering concepts at a young age. Over the past ten years, the Next Generation Science Standards (NGSS) have been integrated into state school curricula, increasing the emphasis on engineering in K-12. Although the NGSS helps introduce engineering at a young age, it can be difficult for teachers to incorporate engineering into their lessons without the required background knowledge. To help mitigate this challenge, a community engagement project was created, bridging a university with a local school district to help fourth-grade teachers incorporate engineering lessons into their classrooms. Engineering and education majors co-taught lessons to fourth-grade students about engineering, wind energy, and the engineering design process. The fourth-grade students applied the engineering design process to build model wind turbines showcased at a celebration event. This study seeks to understand fourth-grade students' perceptions of an engineer before and after participating in this project. Students completed a pre- and post-intervention assessment where they needed to answer the question, "What is an engineer?" Utilizing a constructivist approach, we examined students' knowledge development based on their lived experiences. Our analysis compares pre- and post-intervention responses, considering their experiences within the context of the community-engaged project. We found that students described engineering differently between the pre- and post-intervention responses, and they described engineers with more words related to the engineering design process. This helps us understand the impacts of the community-engaged project on students' perceptions of engineering, which can help inform future educational initiatives that may enhance engineering literacy among K-12 students.

Introduction

To ensure that engineering solutions are effective, inclusive, and innovative and to meet the complex challenges of the future, we need to increase the number of students studying engineering and diversify the workforce [1]. To address this need, there has been a call to include engineering in the K-12 curriculum to enhance engineering literacy and improve career readiness for students interested in matriculating into a post-secondary engineering program [2]. The goal of encouraging more students into engineering is challenging due to the limited knowledge students have about engineering and engineers. A 2011 study asked students to draw an engineer and interviewed some students about their drawings. They found that most students described engineers as a mechanic, laborer, or technician, with few students describing an engineer as a designer. In addition, students predominantly drew engineers as men [3]. This misconception of engineers and engineering makes it difficult for students to picture themselves as engineers, which means students who may enjoy engineering might not consider it a viable career option.

Since the Capobianco et al. 2011 study, there has been an increase in engineering curriculum in K-12 spaces due to many states adopting the Next Generation Science Standards (NGSS). The

Next Generation Science Standards were created to guide teaching and learning in science for the following decade [4]. The NGSS includes engineering learning standards across all grade levels from Kindergarten to twelfth grade [5]. It has been shown that introducing students to engineering in elementary school boosts their interest in potential engineering careers [6].

This study focuses on a community-engaged project that united a school district and a local university. Engineering and education majors at the university collaborated to co-teach lessons to fourth graders about wind energy and the engineering design process. The project aimed to help teachers incorporate the NGSS in their classrooms and get fourth graders excited about engineering. The fourth-grade students learned about engineering, wind energy, and the engineering design process, and they built model wind turbines to test and display at a celebration event at the conclusion of the project. The fourth graders took a pre- and post-intervention questionnaire asking them, "What is an engineer?" Therefore, the purpose of this study is to understand fourth-grade students' understanding of an engineer before and after participating and engaging in a multi-week engineering project. This study is guided by the following research question:

> **RQ:** How do fourth-grade students' perceptions of an engineer evolve after participating in a multi-week community-engaged engineering project?

Background Information

What is an Engineer?

We need to ground our definition of engineering to evaluate students' perception of an engineer. We will ground our definition of engineering around literature focused on the K-12 space. The National Academies of Sciences, Engineering, and Medicine's *Building Capacity for Teaching Engineering in K-12 Education* states that engineering is the knowledge of creating and developing products and processes that are designed under specific constraints. The report further outlines the fundamental characteristics of engineering, highlighting qualities such as purposefulness, iteration, team focus, creativity, and more [2]. An understanding of engineering is necessary to understand what an engineer is. In the National Academy of Engineering's *Changing the Conversation: Messages for Improving Public Understanding of Engineering* report, they state that students have a basic understanding of engineers. Students generally understand that engineers "design and build things," but their knowledge is limited beyond that [7].

The study by Capobianco et al. showed that students primarily described engineers as mechanics, laborers, or technicians. Students often used the word 'engine' to describe an engineer fixing, helping, or repairing a car/engine. This study acknowledged that students were mostly talking from experience. For example, they would describe their dad, uncle, or grandfather fixing a car and associate that with engineering [3]. Demonstrating that students frequently link their definition of an engineer to personal experiences underscores the importance of exposing them to engineering. This exposure helps develop their understanding of what an engineer is.

Education Intervention

To help fourth graders develop an understanding of engineering and engineers, they participated in multiple lessons to learn and actively practice engineering through a community engagement project that partnered a university and its local school district. The project was inspired by the need to support the local school district in meeting its newly adopted Next Generation Science Standards [8], which included an engineering curriculum for Grade 4. The district recognized a gap between the teachers' science training and the engineering concepts outlined in the NGSS, prompting the development of a community engagement project linking engineering and education departments from the university. The engineering and education faculty leading the project selected wind energy as the application area because of its relevance to the region and ability to be tied to the NGSS performance expectations.

A two-tier model was used to bridge the gap between the teachers' training and the new expectations for teaching engineering. First, Grade 4 teachers were invited to the university's campus for a day-long professional development workshop centered around the NGSS engineering learning outcomes and their intersection with designing wind turbines. The second tier of the intervention was to provide demonstration lessons in the Grade 4 classrooms that were planned and taught by interdisciplinary teams of engineering and education majors.

The engineering and education faculty members developed a five-lesson arc of topics adapted to the appropriate grade level from KidWind's WindWise Education curriculum [9] for the undergraduate participants to follow when designing and implementing their hour-long lessons. The five-lesson arc began with the topic of energy and energy transfers (lesson 1), followed by lessons about what causes wind (lesson 2), the engineering design process (lesson 3), and building and testing turbine blades for mechanical and electrical energy (lesson 4), and finally concluding with iterating and finalizing blade design (lesson 5). The students brought their model wind turbines to a culminating celebration event on the university's campus. Throughout the project, the engineering and education faculty reviewed each interdisciplinary team's weekly lesson plan and provided feedback. Revised lesson plans were shared with the Grade 4 teachers before weekly lesson delivery.

Theoretical Framework

This study is grounded in the theoretical framework of constructivism. Generally, constructivism is the belief that for a learner to develop understanding, they need to be actively engaged in the process of meaning-making [10]. Many scholars have shared their definitions of constructivism along with defining characteristics of the theoretical framework, and this study will consider constructivism as defined by Jean Piaget. Piaget posits that learning does not occur passively; learners actively construct meaning by making sense of new information with information they already know [11]. In learning, the learner's prior knowledge contributes to the new knowledge they are forming, and they are constantly negotiating their understanding against what they already know, thus staying active in the learning process [12]. Constructivism will be operationalized in this study by considering the pre-intervention responses as knowledge students already have and the post-intervention responses as the knowledge they constructed after participating in multiple engineering lessons focused on wind energy, engineering, and the engineering design process.

Methods

This study is part of a larger community-engaged collaboration between a small university in Rhode Island and a school district in the area. For this project, an engineering and an education class from the university collaborated to co-teach lessons to fourth-grade students about engineering, wind energy, and the engineering design process. Over the course of a semester, eleven fourth-grade classes across four elementary schools participated in five engineering lessons and a celebration event. During this time, the fourth graders worked in teams to design and build a model wind turbine to test at the final celebration event.

Participants

The participants in this study are fourth-grade students who participated in the engineering lessons as part of the community engagement project. For this project, we obtained approval from the university's Institutional Review Board (IRB). We received consent from the student's parents for them to participate in the lessons and for their data to be used for research purposes. In total, 243 fourth-grade students participated in this project. The school district was chosen based on its proximity to the university and its involvement with the community. The school district hosts students from the university for science fairs, student teaching placements, and a variety of volunteer extracurriculars, so the school district was already familiar with the university.

Data Collection

The primary data sources used in this study are the fourth graders' pre- and post-intervention questionnaire responses. The university's engineering and education faculty developed the questionnaire, which was adapted from existing assessment tools found in the literature. The purpose of the questionnaire was to evaluate fourth graders' knowledge of engineering and how it changed before and after participating in the engineering lessons, which we are considering the intervention. The questionnaire can be broken into three parts. The first part includes questions related to engineering generally and the fourth-grader's beliefs that they can help solve big problems with engineering, with prompts adapted from The Ripple Effect Project in New Orleans [13]. The second part focuses on the engineering design process, with questions adapted from The Boston Museum of Science [14]. Here, students were challenged to use their new engineering knowledge and solve engineering design problems. Finally, the third part asked fourth graders questions about wind energy, again drawn from an assessment tool developed by the Boston Museum of Science [15], which was the main application of the lessons they participated in.

Data Analysis

The fourth graders completed the questionnaire in their classrooms before the five lessons were taught by university students and following the final celebration event at the end of the project, and their written responses were collected by the project team. One of the education research assistants working on the project transcribed all of the fourth grader's responses into a spreadsheet as they were written. The fourth graders' responses had many spelling errors, so, during the analysis process, we needed to make some assumptions about what the students were trying to say.

In order to understand how fourth graders' perceptions of an engineer changed, the data was coded to identify themes and reduce the data into meaningful segments [16]. We analyzed the data using an open coding approach to develop a preliminary codebook and identify themes in the data. We collaborated to develop and finalize the codebook, which was used for second-cycle coding. The finalized codebook grouped the codes into parent and child codes, focusing on four major categories that emerged from the data.

The first category of the codebook is ‘practical application of engineering’; in this category, students described specific applications of engineering, such as buildings, cars, wiring, etc., or students described a very physical interpretation of what engineers do, such as building or fixing something. The practical application of engineering aligns with the findings from Capobianco et al.’s study [3]. The second category is ‘innovative aspects of engineering’; in this category, students described the innovative aspects of engineering that we felt aligned with aspects of the engineering design process. This aligns with the National Academies of Sciences, Engineering, and Medicine’s definition of engineering [2]. The third category focuses on the ‘impact and contribution’ engineers make to others and the world around them. The final category describes ‘engineering skills’ students described in their responses, such as teamwork or solving problems. Aspects of this category align with the National Academies of Sciences, Engineering, and Medicine’s definition of engineering for K-12 teachers [2].

Using our codebook, we used an axial coding approach to identify which codes were most dominant and present in the data [17]. The finalized codebook with examples can be found in Table 1. We collaborated to resolve discrepancies after independently applying codes to the data using the finalized codebook. This process included discussing the differences in our code applications and discussing our thought process to determine which codes should be applied. After resolving all discrepancies, we compared the frequency of the codes applied to determine if different codes were applied between the pre- and post-intervention responses. We used a Chi-squared test to compare the frequency of codes applied to the student's pre- and post-intervention responses. This analysis was chosen to assess whether there was a significant change in the distribution of codes applied between the pre- and post-intervention responses [18]. Since the fourth graders participated in the engineering project between taking pre- and post-intervention questionnaires, this can help us determine if the project had a measurable impact on students' perceptions of engineers. The Chi-squared test provided a basis to help us evaluate the effectiveness of the intervention in helping evolve students' understanding and perceptions of engineers.

Table 1
Finalized Codebook

Code	Subcode	Examples of Fourth Grader Responses
Practical Application of Engineering	Builds	A engineer is a person who builds something or makes it better
	Fixes	A engineer is someone who fixes mechanical stuff, like cars, planes, and motorcicles.
	Examples - Civil Engineering	What engineers do is they design stuff like tunnels and buildings
	Examples - Mechanical Engineering	An engineer is someone who works on machanicle things bilds and fices things like cars, tunles, wiring, drive machines and more
	Examples - Wind-related	An engineer is a person that makes windmill's or wind turbine and one of the other types of engineer's can repair cars.
	Examples - Electrical Engineering	An engineer is someone who write computer programs and install wiring.
	Examples - Environmental Engineering	An engineer is a type of worker that designs way to clean or filter water, sometimes they can construct buildings, and they always work as a TEAM.
Innovative Aspects of Engineering	Invents	Is an inventor that trys to make things better or try to make something new.
	Design	An engineer is someone that designs things and then make what they designed.
	Improves	An engineer is someone that trys to find how to improve something and then create a newer version.
	Testing	They always try to improve stuff. They test different solutions.
Impact and Contribution	Makes Contributions to the Community or World	An engineer is someone who helps design things to make the world a better place.
	Safety	An engineer is a person that disines thing to make them better and safer.
	Job	An engineer is a person that designs and builds things as their job.
	Helps others	A engineer is someone that makes things or help someone
Engineering Skills	Math and Science	Engineers make their own inventions with a lot of math and science
	Solves Problems	An engineer is a person that works hard to solve problems using creative thinking.
	Teamwork	They work as a team and they make stuff

Trustworthiness

To address research quality and trustworthiness with the data, we engaged in multiple strategies for validation used in qualitative research [16], [20]. To address credibility, we debriefed our interpretation of the data and the research process. This included developing independent preliminary codebooks in the initial coding cycle and debriefing our findings to create the finalized codebook. We needed to agree on the codebook and descriptions to move forward. To address dependability, we developed a robust coding process and method for the first and second-cycle coding sessions. Additionally, we established inter-rater reliability by checking if we applied similar codes to the same data. Two authors used the finalized codebook to apply the codes to the fourth grader's responses. To compare our applications of the codes to the data, we calculated the Cohen's Kappa statistic for each code application. Cohen's Kappa is used to evaluate the reliability of inter-rater agreement, adjusting for chance [19]. A statistic above .80 (or 80%) indicates near-perfect agreement, with .61 to .80 (or 61% to 80%) as substantial agreement [19]. Table 2 shows Cohen's Kappa statistic for each code application. As can be shown, the majority of the codes have a Kappa statistic above 61%, showing substantial agreement. The cells highlighted in gray show scores with very little agreement; however, after investigating those specific code applications, it was found that the lower scores are attributed to the codes being rarely applied.

Table 2

Cohen's Kappa for Each Code Application

Code	Subcode	Cohen's Kappa, Pre-	Cohen's Kappa, Post-
Practical Application of Engineering	Builds	86.69%	75.15%
	Fixes	83.43%	85.07%
	Examples - Civil Engineering	82.07%	100.00%
	Examples - Mechanical Engineering	85.66%	83.35%
	Examples - Wind-related	39.37%	86.93%
	Examples - Electrical Engineering	81.98%	27.20%
	Examples - Environmental Engineering	56.16%	85.44%
Innovative Aspects of Engineering	Invents	65.95%	72.28%
	Design	96.22%	91.65%
	Improves	87.41%	92.02%
	Testing	79.68%	100.00%
Impact and Contribution	Makes Contributions to the Community and World	52.87%	90.98%
	Safety	not applied	0.00%
	Job	0.00%	0.00%
	Helps others	76.39%	72.24%
Engineering Skills	Math and Science	100.00%	100.00%
	Solves Problems	88.20%	84.55%
	Teamwork	83.47%	98.32%

Note: The gray cells highlight low Cohen Kappa values; however, those codes were very rarely applied, which caused the statistic to be low. The statistics with a value of 0% were rarely applied, with some discrepancies.

Limitations

Considering the limitations of the data is important to understand how they may impact the analysis process or the results. Some limitations of the data include assumptions that needed to be made about students' spelling and missing data from students between the pre- and post-intervention. The fourth grader's responses were transcribed into a spreadsheet by one of the research assistants on the project. It was important to keep the data as accurate and consistent as possible; however, this process introduced potential subjective interpretations of misspelled words or ambiguous responses. For example, we assumed a response that included "disines" meant "designs." We sounded out the misspellings to try and infer the word the students were trying to spell, but this could have led to some misinterpretations. Additionally, 243 fourth graders participated in the project, but not all students completed the pre- and post-intervention responses, which limited our ability to compare changes in responses at an individual level. Some parents and students chose not to participate in the study, and with the addition of class absences, 153 students completed the pre-intervention questionnaire, and 182 students completed the post-intervention questionnaire.

Results and Discussion

The results discuss the statistical tests applied to the data and our observation of the frequency of the codes applied. Table 3 shows the frequency of the codes applied to the pre- and post-intervention responses.

The Chi-squared test was calculated to compare the frequency of the codes applied to the pre- and post-intervention responses. A significant difference was found, $\chi^2(17) = 42.72$, $p < .001$. This shows that the application of the codes was different between the pre- and post-intervention responses, which suggests that the intervention influenced students' perceptions of an engineer in some way. In addition to the Chi-squared test, we conducted pairwise comparisons between the frequencies of each code applied to the pre- and post-intervention responses to help us determine if there were significant differences in their application before and after students participated in the engineering project. The only code with a statistically significant difference is the "Example - Electrical Engineering." This suggests the intervention did not significantly affect all coded categories. These results may be attributed to the relatively small frequencies of some codes, which could limit the statistical power needed to detect differences. These results suggest that the intervention's impact on the student's responses was nuanced and not widespread across all the codes.

Although we did not observe statistically significant differences between the frequency of individual codes, we observed differences between the application of codes on the pre- and post-intervention responses. As shown in Table 3, most of the code applications were relatively similar or had relatively small frequencies. However, we can observe that some codes were applied more often for the post-intervention responses. For example, the number of times the code "Design" was applied between the pre- and post-intervention responses increased from 41 to 77. Additionally, all child codes in the Innovative Aspects of Engineering parent code were applied more often for the post-intervention responses. Although not statistically significant, we highlighted the codes applied more often for the post-intervention responses in Table 3.

Table 3
Frequency of Codes Applied

Code	Subcode	Frequency Pre-	Frequency Post-
Practical Application of Engineering	Builds	70	79
	Fixes	34	25
	Examples - Civil Engineering	17	17
	Examples - Mechanical Engineering	28	18
	Examples - Wind-related	2	8
	Examples - Electrical Engineering	21	6
	Examples - Environmental Engineering	5	4
Innovative Aspects of Engineering	Invents	21	29
	Design	41	77
	Improves	20	33
	Testing	3	7
Impact and Contribution	Makes Contributions to the Community and World	5	19
	Safety	0	1
	Job	2	3
	Helps others	10	9
Engineering Skills	Math and Science	5	1
	Solves Problems	10	16
	Teamwork	24	37

Note: The gray cells show the codes that were applied more often in the post-intervention responses compared to the pre-intervention responses.

We anticipate that the fourth-grade students' perceptions of an engineer changed before and after participating in a multiple-week engineering project. By participating in KidWind, students were exposed to the engineering design process, teamwork, and the idea of using engineering to help make a difference. Through the lesson plans developed by the university team, the fourth graders were challenged to work together and follow the engineering design process to design and create wind turbine blades. Students can actively develop their understanding of the profession by participating in engineering projects. This aligns with the cognitive constructivist approach to engineering education that suggests when students have an active involvement with new experiences, their understanding of their existing knowledge and connections to reality evolve [21].

The NGSS for fourth-grade students states that students should have an understanding of the engineering design process, such as defining a problem and identifying constraints, generating multiple solutions and evaluating how they meet the constraints, and planning and carrying out tests to determine how the design can be improved [4]. These standards align with the activities the students participated in and the evolution of their understanding of engineers between the pre- and post-intervention responses.

Implications and Conclusion

The Next Generation Science Standards were implemented in 2013 and will continue to evolve to support student development better. Although the goal of the overall project was to help teachers feel comfortable implementing engineering lessons in their classrooms to meet the standards, we were also able to see how the fourth-grade students' perceptions of engineering evolved. Students' perceptions of engineers changed before and after participating in the intervention. This shows that exposure to engineering helped improve their understanding of the profession. By being exposed to engineering in elementary school, students better understand the field, which can impact the possible career paths they may pursue [22]. If more students pursue engineering as a career, the engineering field will become more diverse, and a more diverse workforce is critical to help solve complex problems of the future.

We hope this work can show the impact of a community-engaged engineering project on elementary school students and inform future educational initiatives focused on increasing engineering literacy for K-12 students.

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