Article

Understanding the Conceptions of Engineering in Early Elementary Students

Sandra A. Lampley [1,*], **Sarah Roller Dyess** [1], **Michael P. J. Benfield** [2], **Andrew M. Davis** [2],
Sampson E. Gholston [3], **Monica L. Dillihunt** [1] and **Matthew W. Turner** [2]

[1]   Department of Curriculum and Instruction, College of Education, The University of Alabama in Huntsville, Huntsville, AL 35899, USA; sar0022@uah.edu (S.R.D.); dillihm@uah.edu (M.L.D.)
[2]   Systems Management and Production Center, The University of Alabama in Huntsville, Huntsville, AL 35899, USA; pj.benfield@uah.edu (M.P.J.B.); amd0033@uah.edu (A.M.D.); matt.turner@uah.edu (M.W.T.)
[3]   College of Engineering, The University of Alabama in Huntsville, Huntsville, AL 35899, USA; gholsts@uah.edu
*   Correspondence: sandra.lampley@uah.edu

Abstract: There is a demand for more STEM professionals. Early elementary students' conceptions about engineering can influence whether or not they explore STEM career paths and ultimately select an engineering career. This study examined the conceptions elementary students have regarding the work that engineers perform. The research questions were the following: (1) what images do early elementary students associate with engineering and engineers, (2) do these associations vary from grade to grade, (3) are there gendered differences in these associations, and (4) how do the associations from this sample compare with the associations from the broader (grades one–five) Cunningham, Lachapelle, and Lindgren-Steider (2005) sample? Survey data from 1811 students in grades one–three were analyzed by comparison analysis and cluster analysis and then compared to the initial Cunningham et al. (2005) study. The results indicate two ways elementary students envision engineering: (a) creating designs or collecting and analyzing data, and (b) utilizing equipment to build and improve things. Comparison with the Cunningham et al. (2005) study suggests that there may be shifts in the way elementary students perceive engineering. Since these shifts could be attributed to a variety of factors, future work that determines what learning experiences might be contributing to students' conceptions about engineering is recommended.

Keywords: STEM education; early childhood education; students' conceptions; engineering

1. Introduction

In order to meet the demands of a growing STEM workforce in the United States the National Research Council [1] has called for improvements in K–12 STEM education. Of particular concern is the discipline of engineering, which accounts for approximately 30% of all STEM jobs [2]. However, many students do not consider engineering a possibility because they have had little to no exposure to the subject in their K–12 education [3]. Additionally, the literature indicates that oftentimes students have a limited understanding of engineering and the work that engineers do [4]. For example, many K–12 students describe engineers as train drivers, auto mechanics, construction workers, and people who use large machines [5,6]. The National Academy of Engineering also claims that although most students have a positive impression of engineers, many feel that they are not "smart enough to become engineers" [7] (pp. 6–7). Additionally, many students believe that work done by engineers is sedentary, computer-based, and done in isolation [7], which is not always accurate. Some researchers argue that a child's early attitudes towards engineering are critical in developing a propensity toward engineering education [8]. Furthermore,

a child's conception of engineering and the type of work that engineers do are believed to play a critical role in the decision to pursue or not pursue an engineering career [8].

1.1. Theoretical Framework

A student's conception of a topic can be influenced by a variety of factors. Osborne and Wittrock [9] posit that children are able to develop ideas about their world, construct meanings for words used, and develop strategies to construct explanations for how and why things work as they do. These beliefs, meanings, and explanations work together to form the basis of the term conceptions [9]. Students' conceptions are influenced by daily interactions with their friends, family, environment, and school-related activities (both in school and after school) [9]. These conceptions can develop long before students are formally taught a discipline, therefore making some conceptions sometimes subtly and sometimes dramatically different from the views of scientists [10].

The way that conceptions develop also aligns with a constructivist perspective that explains that learning takes place when individuals form their own understandings; therefore, it is strongly affected by the content and organization of an individual's prior knowledge [11]. It is believed that this prior knowledge plays a critical role in students' learning of new information [12]. Furthermore, students' prior knowledge, or their conception, about a profession can influence their decision to pursue a particular career. For example, in a 2012 study the researchers reported that when middle school students watched recorded video interviews with STEM professionals there was a positive impact on their interest in STEM careers because they were able to learn more about the career [13], thus helping the students develop a more accurate conception of STEM professions.

A more recent framework used to understand career choices is Lent and colleagues' [14] social cognitive career theory (SCCT). According to SCCT, the choices people make and the application of those choices are related to their interests [14]. Lent and colleagues propose that career interests develop over time as individuals process information received through their experiences to develop perceptions about their abilities (self-efficacy), expected results of their actions (outcome expectations), and their career goals. Personal inputs (e.g., gender, race/ethnicity, and age/grade level) and background contextual affordances (e.g., parental support, role models, and perceived barriers) are also believed to influence learning experiences, and can also influence self-efficacy and outcome expectations, both of which form the basis for developing career interests. Within the SCCT framework displayed in Figure 1, conceptions of engineering would be developed based on learning experiences in STEM. Constructivists believe that it is during these learning experiences that individuals build their own conceptions of engineering as they make sense of the work that engineers do. These conceptions can also be influenced by their personal inputs and background environmental influences. For students, these learning experiences include formal school experiences (e.g., STEM classes), structured after-school or summer experiences (e.g., robotics clubs, STEM camps), as well as more informal experiences that occur with family and friends (e.g., family vacations, museums, building projects at home, and observations of parents who are engineers). Thus, while SCCT suggests that interest, self-efficacy, and outcome expectations may drive whether or not a person decides to pursue a STEM career, this decision may also be linked back further to the conceptions that students develop about STEM, which can begin forming at an early age.
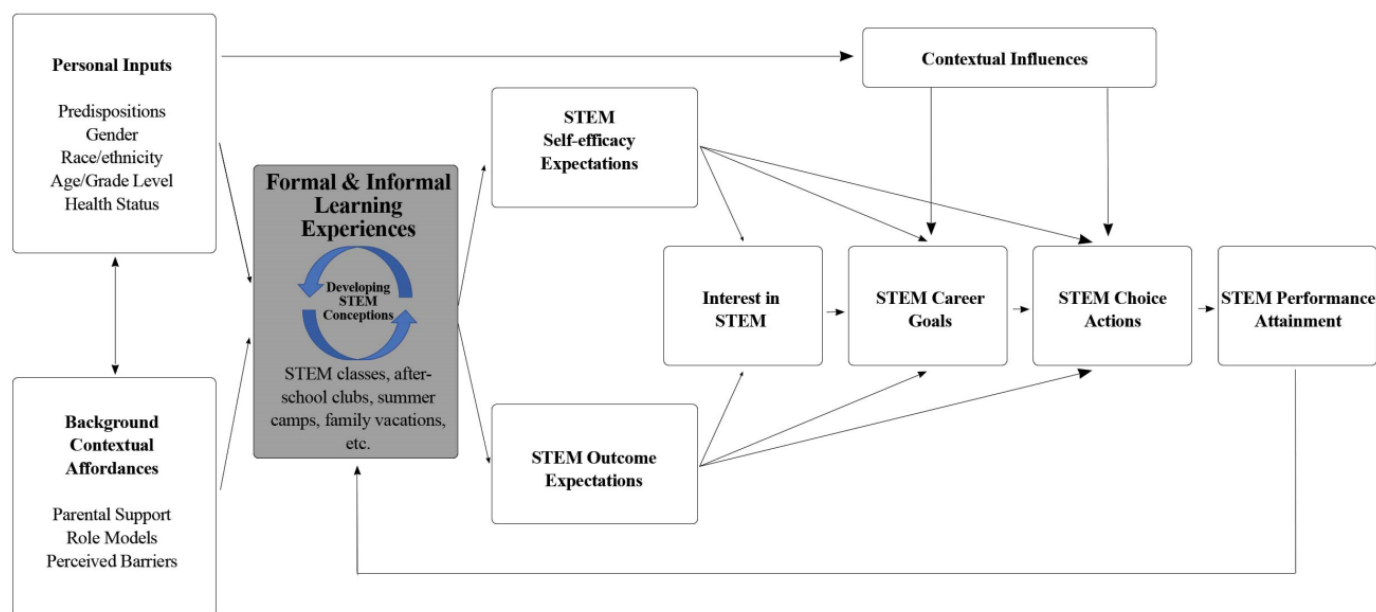
Figure 1. SCCT framework with the inclusion of students' conceptions, which are developed based on formal and informal learning experiences. Adapted from [15,16].

1.2. Learning Experiences Inform Early STEM Conceptions

The literature indicates that early STEM experiences (defined as preschool through to the third grade) play an important role in enhancing a child's knowledge, skills, and dispositions, which are necessary in order to prepare them for the jobs of the future [17–19]. Furthermore, students who have an increased interest in science, mathematics, and engineering during these years are more likely to pursue that interest, resulting in a STEM-related career [20]. Unfortunately, science—much less engineering—is rarely introduced to early childhood students in a meaningful way [21]. Fortunately, there are multiple avenues outside of a formal school setting that are available for exposing students to STEM at an early stage, which could also help children develop accurate conceptions of engineers and the work that engineers do.

For example, informal STEM learning experiences can provide opportunities that build students' conceptions of and interest in the STEM fields in an engaging and hands-on way [20]. Informal learning experiences can include programs led by museums, libraries, and community-based organizations that provide after-school or summer programs. While participating in these informal spaces students are exposed to STEM experiences that allow for student-driven exploration, where they are able to experience experimentation and failure while developing strong relationships with mentors and peers. During this process students increase their knowledge and skills, which are vital if one wants to persist in a STEM field [20].

Additionally, parents and family members can also play an important role in their child's STEM learning experience and STEM conceptions. Approximately seven out of ten engineers in the United States claim to have a relative that was an engineer [8]. Additionally, younger children are naturally inclined to tinker, create, and participate in the natural design process while also developing lasting attitudes about science [22]. During this time, children spend a significant amount of their waking hours outside of the school setting [23]. Furthermore, much of the general public are uninformed about engineering and the work that engineers do [8]. Therefore, Dorie et al. [24] suggest that educating parents about engineering is important; if a parent cannot articulate what an engineer is to their child, they may be less likely to encourage their children to explore the discipline, which can lead to an unintentional impact on the attitude of the child toward engineering.

1.3. Students' Conceptions of Engineering

While the field of pre-college engineering is relatively new, there have been several studies that examined students' conceptions or perceptions about engineering [6,25–27] in addition to others that focused specifically on early elementary students' conceptions [5,28–31]. Some of the studies utilized student drawings while others employed open-response items, Likert-scale questions, or existing drawings, where students marked whether each picture was engineering or non-engineering. This section will summarize the instruments used to measure students' conceptions about engineering, including an overview of students' conceptions for each study, and is organized based on the survey type.

The Draw An Engineer Test (DAET) has been a popular test used to gather students' conceptions of what an engineer does [5,6,26,28,31]. The DAET is an adaptation of the Draw A Scientist Test (DAST) [32], which was developed to determine the age that children start to develop distinctive images of scientists. The DAET consists of a prompt that asks students to draw a picture of an engineer at work. Additionally, it includes question prompts, such as "In your own words, what is engineering?" and "What does an engineer do?".

The DAET was first utilized by Knight and Cunningham [6] for students in grades three through twelve. Of the 385 participants in this study, 16% were in grades three through five. Students in this study, especially the younger students (grades three–five), believed that "engineers use tools to build buildings and fix car engines" (p. 7). Knight and Cunningham believed this was due to an issue in understanding vocabulary. Specifically, many students made statements about the term "engineering" having the word "engine" in it, leading them to believe that engineers must work with engines, specifically car engines. In the same study, older students were more inclined to think that engineers are involved in "designing things, such as buildings and machines" (p. 7). Additionally, when gendered characteristics were examined in the drawings, most associations were male-related.

Capobianco et al. [5] also used the DAET to examine students' conceptions about engineering in 396 participants in grades one–five. Students in this study mostly conceptualized an engineer as a mechanic, laborer, and technician. Additionally, students believed that an engineer was "restricted to fixing, building, making, or working and using artifacts such as vehicles, engines, buildings, and tools" (p. 323). There was a small percentage of students in the fourth and fifth grades (17%) who believed that an engineer is someone who designs things. In terms of gender, 58% of students drew male engineers and 18% drew females, while the remaining 24% drew groups of engineers or engineers with no distinguishing gendered features.

Fralick et al. [26] used the DAET and DAST to see how student perceptions of engineers compare/contrast with their perceptions of scientists in sixth through eighth grade students. Approximately 1600 drawings were analyzed for this study: 928 associated with the DAST and 744 associated with the DAET. In this study, students' images mostly displayed engineers as "doers" or "worker bees", with many drawings showing the engineer with many civil structures, building tools, and vehicles. Most of the drawings represented engineers as performing "lower-level mental functions and physical actions (operating, making) rather than higher level mental functions (explaining, experimenting)" (p. 6). Additionally, many students in the study did not draw an action associated with the engineer, compared to several actions they associated with the scientist (making, operating, explaining, designing, experimenting, and observing). Fralick et al. believe that this indicates that perhaps students lacked conceptual understanding rather than possessing an inaccurate conception of the work that engineers do. Finally, when a gender could be determined in students' drawings the gender was predominantly male, with the engineering pictures showing a higher percentage of males than the scientist drawings.

The DAET has also been used as a pre/post-survey to assess change in students' conceptions of engineering after participating in an informal learning experience. For example, Oware et al. [31] used the survey as a pre/post-assessment to examine the conceptions of third and fourth grade students who participated in a summer engineering experience. Although the sample size was small (n = 15), the results indicate that students'

conceptions about engineers changed to more accurate conceptions from the first day of the experience to the last. At the end of the camp experience, the participants stated that engineers did things such as build, design, fix, test, and invent. The authors did not discuss gendered associations in the participants' drawings. It is important to note that all participants in this study were male.

Similarly, Carr and Diefes-Dux [28] utilized the DAET as a pre/post-assessment for 173 students in grades two–four after receiving year-long instruction from teachers that participated in a professional development in elementary engineering. The results of this study also indicate a change in students' conceptions from pre/post. Specifically, there were less students in the post-assessment who believed that engineers were mechanics or laborers/builders, and more students who believed that engineers were designers. Despite this change, there were still a considerable number of students who continued to believe that engineers were laborers/builders and mechanics in the post drawings. This study also showed that many students were able to transfer the engineering design concepts beyond classroom activities in their drawings. For example, rather than drawing an engineer designing a windmill, which was a classroom activity, many students were able to draw someone designing other things, such as bicycles, safer playgrounds, etc. This study did not look at associations with gender in students' conceptions.

While the DAET is a useful tool for a first diagnosis of students' conceptions, it has some limitations. Students only draw one image, which does not provide a full understanding of the breadth of students' understandings of what engineers do. Additionally, analyzing the data of such an instrument can be time-consuming when surveying hundreds or thousands of children.

There have been other surveys that have been created to determine students' conceptions of engineering. Gibbons et al. [27] designed a survey to assess students' knowledge and attitudes toward engineering in middle school, called the *Middle School Students' Attitude to Mathematics, Science, and Engineering* survey. One section of the survey asked students to list five types of engineers and an example of work done by each. Of the 1701 students, only 54 (approximately 3%) could correctly name five different types of engineers. Another four percent correctly named four different types of engineers, but 51% of the students either gave no response or none of their responses were correct. Additionally, none of the students were able to give five completely correct examples of the type of work each type of engineer does, with 65% of the students giving either no response to the second part of the question or giving responses that were all incorrect. These authors did not examine gendered differences for this study.

Lachapelle et al. [30] developed another instrument, titled the *What is an Engineer Test*, to measure 1126 third and fourth grade students' changes in conceptions after participating in an engineering unit. The instrument consists of 58 items that are divided into two categories. Thirty-seven items relate to the question "Are these things that an engineer would do for his or her job?" (paragraph nine). The remaining 21 items are listed under the question "How important are each of the following activities to the work of an engineer?" (paragraph nine). In this study, "students were more likely to say that engineers repair or install things like cars or electrical items than they were to say that engineers improve or invent things that are not electric or having to do with cars" (p. 10). Lachapelle et al. concluded that students were focusing more on what was being worked on rather than what sort of work was being done. The authors of this study did not examine gendered differences in the data.

While the previous two surveys required participants to read each item, Cunningham et al. [29] developed a survey for students in grades one–five that was designed with pictures to overcome reading limitations in order to determine students' conceptions of engineering and technology. The instrument consists of 32 images and descriptions of people at work; the engineering portion consisted of 16 images, and the technology portion also consisted of 16 images. In the engineering portion of the survey students were asked to circle the types of work engineers do (for the first 16 images) complete the following

statement: "An engineer is a person who . . . " (paragraph six). The technology portion of the survey also had 16 images, in which students were asked to circle the items that involved technology. Additionally, students were asked to answer the following question: "How do you know if something is technology?" (paragraph seven). Due to being designed this way, the instrument can be scored easily and used to assess students' initial conceptions, as well as growth in engineering and technology conceptions. Cunningham et al. [29] administered the two instruments to over 6000 students and reported findings from a random sample of 504 students. Over half of students indicated that they thought engineers repair cars, install wiring, drive machines, construct buildings, set up factories, and improve machines. Fewer students thought that engineers supervised construction, designed things, and worked as a team. This study did not examine differences in students' conceptions in engineering between genders. In sum, students' conceptions of engineering can begin developing at an early age based on a multitude of informal and formal learning experiences that are not always known. Conceptions of early elementary students can be difficult to gather due to the readability of surveys, and even the DAET has only gathered information from grades two–four. The goal of the current study is to contribute to the existing data of students' conceptions of engineering, specifically by examining how early elementary students (grades one–three) conceptualize the work that engineers do. Additionally, this study also investigates how these conceptions compare/contrast to the results of the Cunningham et al. [29] study that occurred over a decade and a half ago and with a broader grade span. Learning about early elementary conceptions of engineering can provide insights into the ways students make sense of engineering, which could impact their decisions to pursue engineering careers.

1.4. Research Questions

This research is part of a larger NSF-funded project investigating the engineering pipeline, particularly the challenges and barriers facing K–12 students to pursue engineering as a career. The purpose of this study is to understand the conceptions that early elementary students (grades one–three) have regarding the work engineers perform by investigating the images they associate with engineering. Four research questions guided the work: (1) what images do early elementary students associate with engineering and engineers, (2) do these associations vary from grade to grade, (3) are there gendered differences in these associations, and (4) how do the associations from this sample compare with the associations from the broader (grades one–five) Cunningham et al. [29] sample?

2. Materials and Methods

2.1. Context of the Study

The data analyzed in this study were part of a larger state-wide project investigating the engineering pipeline challenges facing K–12 students. The research project occurred in a southeastern state of the U.S. during the 2018–2019 and 2019–2020 school years. Science standards that included engineering standards (similar to the Next Generation Science Standards) [33] had been adopted by the state in 2015, and each school was responsible for addressing these standards in their curriculum. Prior to the 2015 standards the state did not have engineering standards.

2.2. Data Collection

School systems within a southeastern state of the U.S. were contacted to determine their interest in participating in this study. Once the superintendent of each school system agreed to participate the district office provided the names of every teacher and the number of students in their classroom for each school in their system. Survey packets were created and distributed to each teacher, which contained a parent consent form, parent survey, and a student survey. Teachers were instructed to give the consent form and parent survey to the parents of each student in their class. Once the consent form was returned to the teacher

the student was instructed to complete the survey instrument, which was then returned to the researchers for evaluation.

The Cunningham et al. [29] instrument was distributed to each first-, second-, and third-grade student at the participating schools, and was intentionally selected because the pictures made it less reliant on students' reading ability. Figure 2 displays the images and the prompt that were used for the study.

Figure 2. Survey administered to early elementary students, which utilized the Cunningham et al. (2005) survey items (images and description). Adopted from "Assessing elementary school students' conceptions of engineering and technology", C. M. Cunningham, C. Lachapelle, and A. Lindgren-Streicher, 2005, *American Society of Engineering Education Annual Conference & Exposition Proceedings*, p. 9. Copyright 2005 by the American Society of Engineering Education.

Although the original survey instrument provided a section for the student to explain their selections, this was omitted in the survey. The decision to omit this written section was made in an attempt to minimize the amount of time it would take students to complete the survey and because quantitative methods were going to be used to analyze the large amount of state-wide data. In hindsight this adjustment was a limiting factor that will be discussed later in the paper.

2.3. Sample

A total of fifteen school systems agreed to participate in this research study. The total number of surveys received was 3584, and of these 1811 were used after removing those with missing data. In order to be included in the sample population for this study the student survey and parent survey both needed to be returned so that the researchers could correlate the demographic data parents identified about their child (e.g., gender and race/ethnicity) with the student survey. This resulted in a sample size of 1811 surveys.

Table 1 provides the number of students who completed a survey by grade per school system and the gender of the population. Of the 15 school systems that participated, ten were county systems with a total of 1398 students (77% of the sample) and five were city systems with a total of 413 students (23% of the sample). Participation across the three grades was fairly consistent with 572 first-grade students (32% of the sample), 651 second-

grade students (36% of the sample), and 588 third-grade students (32% of the sample). The male to female ratio was approximately 1:1.

Table 1. Grade and gender distribution of the participating school systems.

School System	First Grade	Second Grade	Third Grade	Total	Male	Female
City 1	9	7	41	57	32	25
City 2	38	29	27	94	53	41
City 3	44	32	14	90	40	50
City 4	22	44	60	126	47	79
City 5	27	19	0	46	18	28
County 1	56	51	25	132	64	68
County 2	13	60	42	115	56	59
County 3	74	47	53	174	94	80
County 4	132	146	131	409	218	191
County 5	42	20	45	107	58	49
County 6	50	71	73	194	88	106
County 7	6	18	25	49	25	24
County 8	23	40	15	78	38	40
County 9	6	31	23	60	29	31
County 10	30	36	14	80	40	40
Total	572	651	588	1811	900	911

There is a varied set of economic backgrounds represented in the school systems sampled, shown in Table 2, with the percentage of free and/or reduced lunch reported on the state's department of education website ranging from 32% (city 2) to 78% (county 5 and county 10). The sample population is diverse, with significant participation from several underrepresented groups. Specifically, Table 2 lists the race/ethnicity demographics of the sample obtained from each school system, based on responses from parents about their children. Collectively, as one sample set, students in the population identified as 54% White (985 students), 37% African American (673 students), 6% Hispanic (101 students), 1% Native American (10 students), and 2% other (35 students).

Table 2. Race/ethnicity demographics for the participating school systems.

School System	Percentage of Free/Reduced Lunch [a]	Asian [b]	Black/African American [b]	Hawaiian/Pacific Islander [b]	Hispanic [b]	Native American [b]	Other [b]	White/Caucasian [b]
City 1	58%	2%	46%	0%	11%	0%	5%	37%
City 2	32%	1%	9%	0%	3%	1%	2%	84%
City 3	33%	0%	8%	0%	47%	0%	2%	43%
City 4	76%	0%	92%	0%	0%	0%	2%	6%
City 5	53%	0%	17%	0%	0%	0%	2%	80%
County 1	53%	1%	0%	0%	8%	0%	1%	90%
County 2	71%	0%	72%	0%	1%	0%	3%	24%
County 3	68%	1%	62%	0%	1%	0%	0%	36%
County 4	51%	0%	22%	0%	3%	0%	4%	70%
County 5	78%	0%	2%	0%	5%	4%	0%	90%
County 6	46%	1%	8%	0%	7%	1%	1%	82%
County 7	52%	0%	61%	0%	0%	2%	0%	37%
County 8	76%	0%	53%	0%	4%	1%	3%	40%
County 9	65%	0%	98%	0%	0%	2%	0%	0%
County 10	78%	0%	99%	0%	1%	0%	0%	0%

[a] indicates data were retrieved for the school district from the state's department of education website. [b] indicates data were retrieved via parent surveys about their child. Percentages are rounded to the nearest whole number. Thus, there is a roundoff error within ±1%.

2.4. Data Analysis

The survey data were analyzed using a comparison analysis and cluster analysis to respond to the research questions. For both analyses, each student's response was coded as either selected or not selected for each image. More specifically, if a student selected an image as representing an activity related to engineering a score of 1 was given, with the absence of a selection given a score of 0. Totals for the entire dataset were summed

for all sixteen images and the percentages of students selecting each image as engineering were calculated. Bar graphs displaying these percentages were used to describe the sample (research question 1) and make some comparisons across grade levels (research question 2).

Hierarchical clustering analysis was performed using Minitab 19 to further respond to research question 1 and research question 2 by identifying images that students similarly associated as engineering or not engineering. Clustering analysis aims to identify similar groups of cases that are more similar to each other than those cases in another cluster. Clustering can be performed with several different techniques; however, for the purpose of this study a hierarchical clustering technique was adopted. Intentionally selected, hierarchical clustering analysis is a technique to find the underlying structure or clustering tendency of objects through an iterative process that associates (agglomerative methods) or dissociates (divisive methods) the objects based on the information contained in the fingerprint matrix [34]. The similarity or dissimilarity between samples is usually represented in a dendrogram, a tree-like diagram that records the sequences of cluster merges or splits. The distance between the splits of clusters is computed based on the length of the straight line drawn from one cluster to another, referred to as the similarity value. Ward's [35] method was used to create the clustering groups.

Tukey's multiple comparison test [36] was further employed to determine how students' perceptions of engineering compared from grade to grade, and also how the students' associations in the current study compared to the previous Cunningham et al. [29] study. Specifically, this test was used to calculate the 95% confidence interval of the percentage of each grade (research question 2), gender (research question 3), and sample (research question 4) that selected an image as engineering, in order to compare populations.

3. Results

3.1. Early Elementary Students' Associations with Engineering

To answer the first research question regarding which images early elementary students associate with engineering and engineers, the survey data from the entire sample were analyzed via two methods: comparison analysis and cluster analysis. Figure 3 depicts the distribution of percentages of students by grade who selected each image as relating to engineering. As seen in the figure, five of the sixteen images (i.e., "design things", "improve machines", "construct buildings", "install wiring", and "set up factories") have a majority (above 50%) of students in all three grades selecting that image as something engineers do. A majority of first graders selected "work as a team" and "design ways to clean water" as something engineers do, while a majority of second graders selected "repair cars" and "drive machines". Conversely, less than 20% of students in each grade selected "arrange flowers", "clean teeth", "make pizza", and "sell food". This indicates that most students did not associate these images with engineering.

When the images are organized from most selected to least selected by students (Figure 3), they create a continuum from engineering to not engineering. To further determine which images early elementary students similarly perceived as engineering or not engineering individual responses were further analyzed via cluster analysis [35]. The agglomeration schedule (Table 3) displays how the hierarchical cluster analysis progressively clusters the observations. Each row in the table shows a stage at which two cases are combined to form a cluster using an algorithm dictated by the distance and linkage selections. The agglomeration schedule lists all of the stages in which the clusters are combined until there is only one cluster remaining after the last stage. The number of stages in the agglomeration schedule is always one less than the number of cases in the data being clustered. In this case there are 15 stages because there are 16 images (items). The similarity value at each stage represents the distance of the two clusters being combined. As shown in Table 3, images 10 ("Make Pizza") and 12 ("Sell Food") are combined at the first stage because the similarity value between them is the smallest out of all the pairs. The difference in similarity values indicates that the clusters being combined at a given stage are more heterogeneous than previous combinations; thus, should be in a different group.
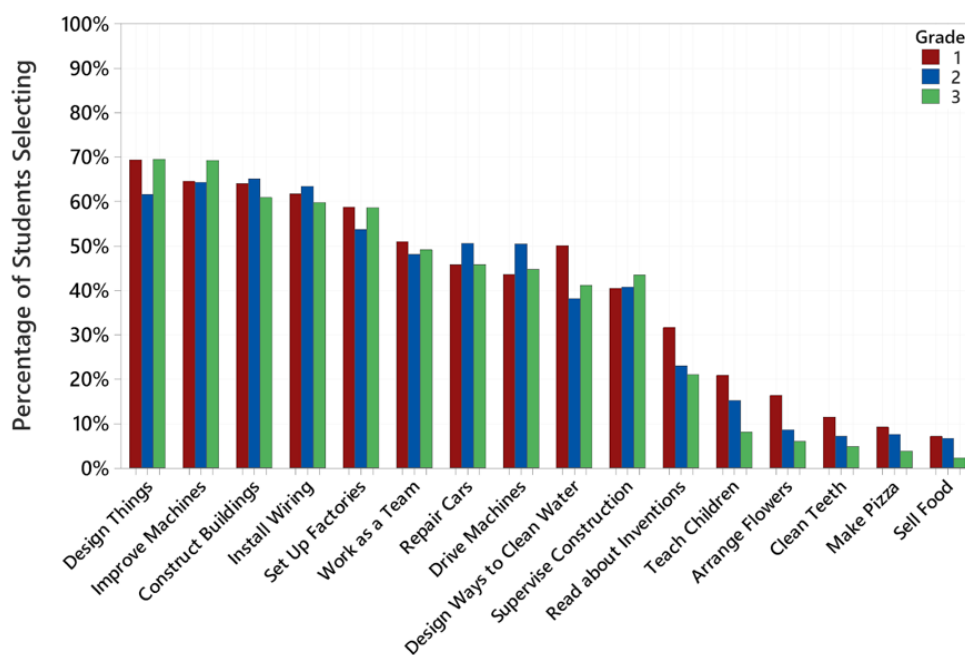
Figure 3. Percentage of students selecting an image by grade.

Table 3. Agglomeration schedule for cluster analysis.

Stage	Number of Clusters	Similarity Value	Distance Level	Clusters Joined		New Cluster	Number of Observations in New Cluster
1	15	77.262	0.45476	10	12	10	2
2	14	76.701	0.46598	10	15	10	3
3	13	71.3386	0.57323	9	14	9	2
4	12	70.8622	0.58276	1	3	1	2
5	11	69.3227	0.61355	5	13	5	2
6	10	68.8805	0.62239	10	16	10	4
7	9	67.6629	0.64674	2	4	2	2
8	8	66.4291	0.67142	8	9	8	3
9	7	66.0223	0.67955	5	11	5	3
10	6	64.5481	0.70904	6	10	6	5
11	5	61.6694	0.76661	7	8	7	4
12	4	55.2173	0.89565	2	5	2	5
13	3	54.7913	0.90417	1	7	1	6
14	2	20.8068	1.58386	1	2	1	11
15	1	−14.7894	2.29579	1	6	1	16

The agglomeration schedule is used to assist in identifying at what point two clusters being combined are considered too different to form a homogeneous group. This is identified by the first large difference in similarity values. Looking at the agglomeration schedule in Table 3, there is a large difference in the similarity values between stages 13 (similarity = 54.8) and 14 (similarity = 20.8). As compared to the other differences between stages, this large difference between stages 13 and 14 (difference = 34) represents a large dissimilarity between clusters. When there is a large difference between the similarities of two consecutive stages, the clusters being merged increase in heterogeneity. This analysis (Table 3) identifies the last stage before dissimilar clusters begin to be merged. That is, the large difference in similarity values between stages 13 and 14 implies that performing stage 14 (that is, moving from three to two clusters) results in dissimilar clusters being merged. Hence, this analysis indicates that the clustering process should be stopped at stage 13, indicating the existence of three clusters. Figure 4 shows a scree plot of the

similarity values versus number of clusters, specifically the change in the slope at cluster three, indicating three cluster groups.
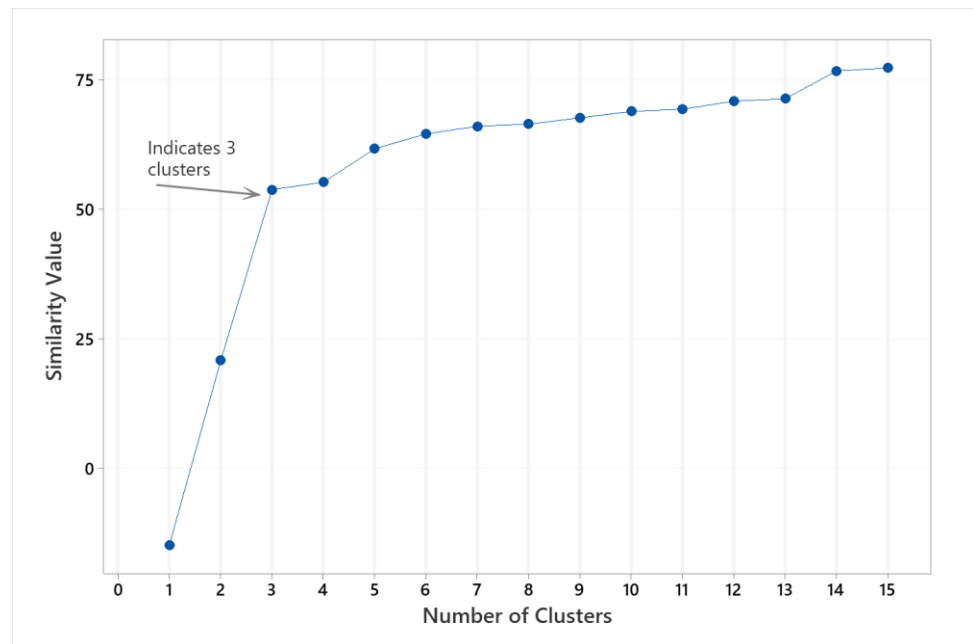

Figure 4. Scree plot of the agglomeration schedule for the entire data sample.

　　Hierarchical cluster analysis is illustrated using a dendrogram, a visual display of the clustering process (Figure 5). Examining the dendrogram from the bottom to the top, clusters that are more similar to each other are grouped together earlier. The horizontal lines in the dendrogram represent the grouping of clusters or the stages of the agglomeration schedule. They also indicate the similarity between two joining clusters. As the clusters being merged become more dissimilar, the horizontal lines will be located closer to the top of the plot, as they represent larger similarity values.
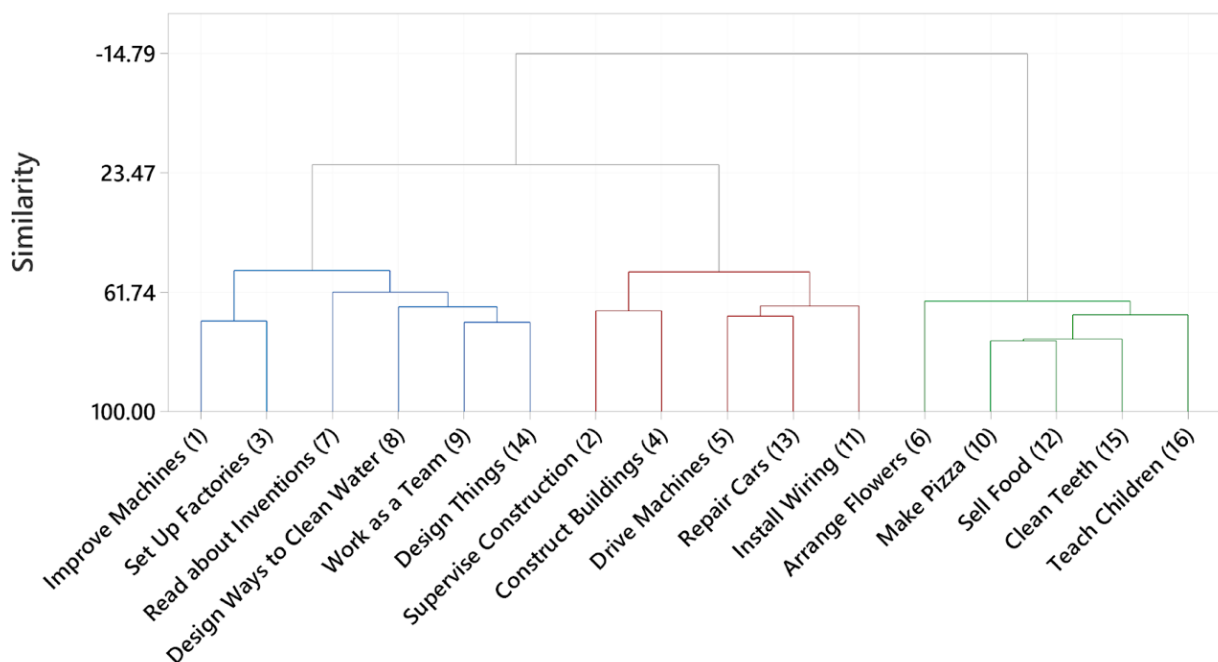

Figure 5. Dendrogram for hierarchical cluster analysis using Ward linkage.

While the horizontal lines are indicative of the similarity values between clusters, the vertical lines represent the differences in these similarity values. The vertical lines also connect all cases that are part of one cluster, which is important in determining the final number of clusters once the decision has been made to stop. Upon visually inspecting the dendrogram, the longest vertical lines represent the largest differences. Therefore, a long vertical line indicates that two clusters which are dissimilar to each other are being combined and can inform where it is optimal to stop the clustering procedure. Similar to the agglomeration schedule, if the vertical and horizontal lines are close to one another then this would suggest that the level of homogeneity of the clusters merged at those stages is relatively stable. The cut-off should thus be placed where there are no closely plotted lines, while eliminating the horizontal lines with large values [37]. The best approach to determine the number of clusters in the data is to incorporate information from both the agglomeration schedule and the dendrogram [37]. Figure 5 illustrates the dendrogram generated in Minitab 19. From the agglomeration schedule, the authors concluded that it would be best to stop the cluster analysis after the 13th stage, thus indicating three final clusters. This decision is reflected in the dendrogram where the last two vertical lines (representing the last stages in the agglomeration schedule) are cut from the cluster solution. By stopping the clustering at this point three clusters are revealed. Since these clusters align similarly with the images students selected or did not select (Figure 3), we defined these clusters as *Engineering A* (blue), *Engineering B* (red), and *Not engineering* (green).

The dendrogram in Figure 5 shows the perceptions of elementary students as they relate to engineering. The numbers in parentheses after each item represent the order in which the items appeared within the survey instrument. Three clusters are presented, which we define as *Engineering A*, *Engineering B*, and *Not engineering*. The *Engineering A* group consists of "improve machines", "set up factories", "read about inventions", "design ways to clean water", "work as a team", and "design things". *Engineering B* consists of "supervise construction", "construct buildings", "drive machines", "repair cars", and "install wiring". The *Not engineering* group consists of "arrange flowers", "make pizza", "sell food", "clean teeth", and "teach children". When looking at the data by grade, Table 4 shows the results of the cluster analysis, providing some insight into the second research question about engineering associations varying from grade to grade. Overall, there was no difference in the views of first- and second-grade students. Third-grade students viewed most of the images similarly to first- and second-grade students with the exception of two images (e.g., "design ways to clean water" and "read about inventions"), which they identified as *Not Engineering*. Although the grade-level cluster analysis demonstrates a difference for these items across grade levels, it might be noted that in Figure 3 only the first grade had at least 50% of students selecting "design ways to clean water" as engineering and none of the grade levels had a majority of students who selected "read about inventions" as engineering. Thus, while these two images in cluster *Engineering A* were defined as *Engineering* by the hierarchical cluster analysis of the whole dataset, the grade-level data in Figure 3 and Table 4 highlight some differences in this classification. Therefore, this disagreement in classification may be highlighting that these images are either more in the middle of the continuum between engineering or not engineering, or that something else may be occurring in the data.

3.2. Grade Comparisons of Images Associated with Engineering

Continuing an exploration of the second research question, Tukey's multiple comparison test [36] was used to calculate the 95% confidence interval of the percentage of each grade that selected an image as engineering. As shown in Figure 6, the 95% confidence intervals for each image per grade reveal that eight of the sixteen images (i.e., "improve machines", "construct buildings", "install wiring", "set up factories", "work as a team", "repair cars", "drive machines", and "supervise construction") were not significantly different by grade.

Table 4. Three cluster results for each grade level.

| Case	First Grade	Second Grade	Third Grade
Install wiring	Engineering B	Engineering B	Engineering B
Design things	Engineering A	Engineering A	Engineering A
Construct buildings	Engineering B	Engineering B	Engineering B
Improve machines	Engineering A	Engineering A	Engineering A
Set up factories	Engineering A	Engineering A	Engineering A
Repair cars	Engineering B	Engineering B	Engineering B
Drive machines	Engineering B	Engineering B	Engineering B
Work as a team	Engineering A	Engineering A	Engineering A
Supervise construction	Engineering B	Engineering B	Engineering B
Design ways to clean water	Engineering A	Engineering A	Not engineering
Read about inventions	Engineering A	Engineering A	Not engineering
Teach children	Not engineering	Not engineering	Not engineering
Arrange flowers	Not engineering	Not engineering	Not engineering
Clean teeth	Not engineering	Not engineering	Not engineering
Make pizza	Not engineering	Not engineering	Not engineering
Sell food	Not engineering	Not engineering	Not engineering
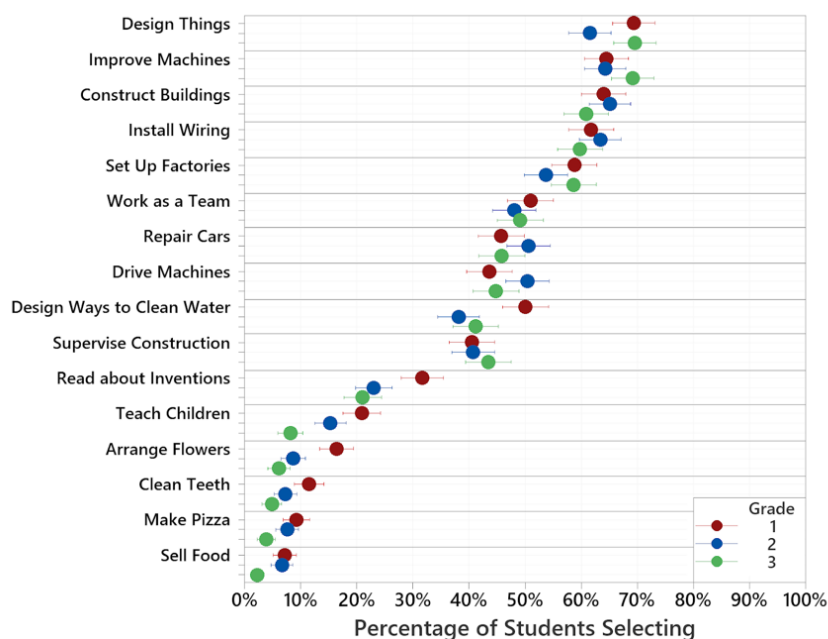
Figure 6. Confidence intervals of 95% for each image per grade.

In contrast to the images that all grades perceived similarly, three images (i.e., "design ways to clean water", "read about inventions", and "arrange flowers") were found to be statistically different between grades one and two as well as grades one and three. In these three images a larger percentage of first graders associated the image as engineering, whereas the second and third graders did not. However, only "design ways to clean water" was selected by 50% of the students in the first grade. The other images were selected by less than 50% of the students in all grade levels. This indicates that, although there was disagreement, the majority of students in each grade agreed that the images did not represent engineering. Three images ("teach children", "make pizza", and "sell food") were also found to be statistically different between grades one and three as well as grades two and three, with the largest percentage being first graders associating the image as engineering. However, with the exception of "teach children", the percentage of students selecting this image was below 10%, indicating that the students typically did not associate this image with engineering. Additionally, it is important to note that the image "design

things" was significantly different between grades two and one as well as grades two and three, with more students in the first and third grades selecting this image as engineering.

3.3. Gender Comparison of Images Associated with Engineering

To address the third research question, regarding gendered differences, Tukey's multiple comparison test [36] was used again to calculate the 95% confidence interval of the percentage of each gender that selected an image as engineering. These data are displayed in Figure 7. Specifically, the graph (Figure 7) reveals that there were no significant differences between the images that male and female students associated with engineering.
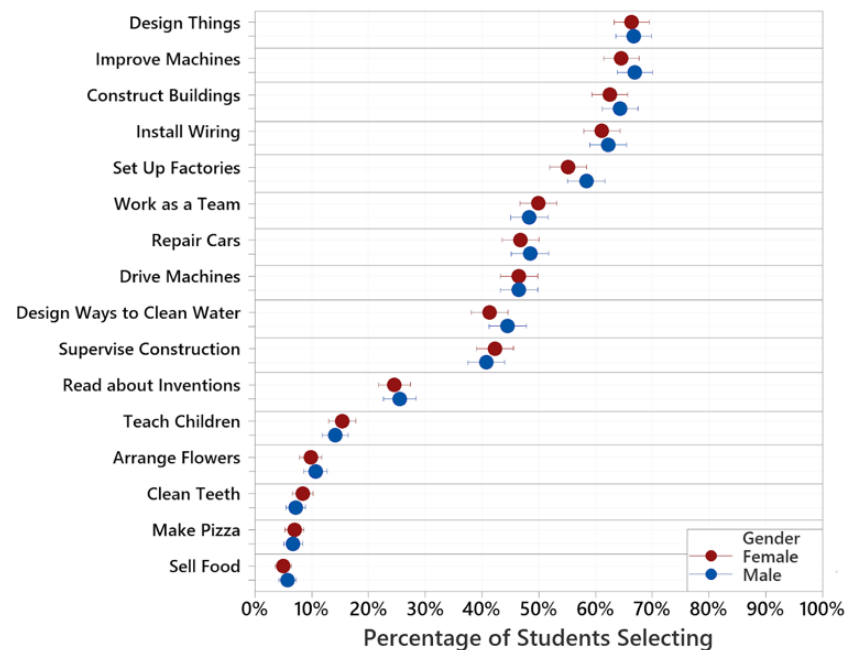

Figure 7. Confidence intervals of 95% for each image by gender.

3.4. Cunningham et al. (2005) Comparison

The last research question was to explore how the associations from this sample compared with the associations from the Cunningham et al. [29] study sample, which is the only known study that uses the same survey. The Cunningham et al. study analyzed responses from a random sample of 504 students in grades one–five, which was a slightly larger range of grade levels than our current study. In order to compare the two datasets, the data from the current study were condensed (all of the selections per image for grades one–three) into one result per activity to provide a direct comparison to the work by Cunningham et al. Figure 8 depicts the results from the Cunningham et al. study in blue, with the current study in red. Similarities and differences can be seen across the 16 images.

Tukey's multiple comparison test [36] was used to calculate the 95% confidence interval of the percentage of each sample that selected an image as engineering. Comparing the 95% confidence intervals (Figure 9) reveals that only three of the sixteen images were not significantly different (i.e., "improve machines", "teach children", and "make pizza"). All of the other 13 activities were significantly different at a 95% confidence level. Several activities that students more closely associated with engineering, such as "design things", "work as a team", "design ways to clean water", and "read about inventions" tended to be selected more by the current study participants and less by the Cunningham et al. study participants. With the exception of "read about inventions" these images' descriptions either share the word "design" or the images display people working together. Conversely, images that students more closely associated with engineering (>50%) but that were selected more often as engineering by the Cunningham et al. participants were "construct buildings", "install wiring", "set up factories", "repair cars", and "drive machines". These images highlight

engineering as working with equipment, requiring instruments, tools, or machinery, for example. Thus, the current group of students may be thinking about engineering as more of a design process that engineers engage in with others, whereas the Cunningham et al. study participants seemed to be more focused on the items an engineer uses or how they build and improve things with tools.
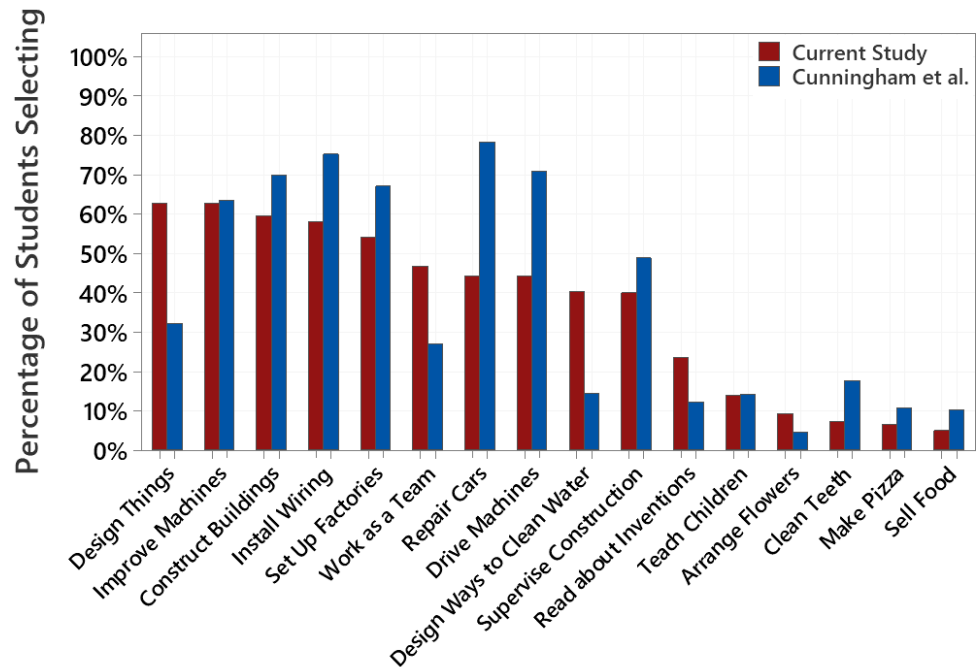

Figure 8. Comparison of Cunningham et al. (2005) data and the current study's dataset.
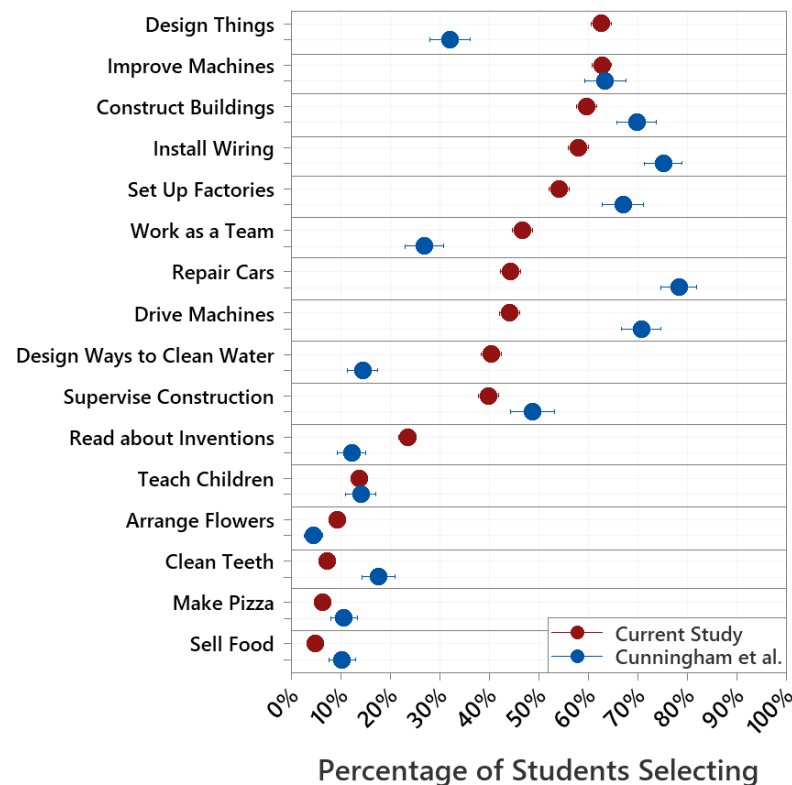

Figure 9. Confidence intervals of 95% confidence intervals for the Cunningham et al. (2005) data and the current study data. Error bars indicate 95% confidence intervals.

4. Discussion

In the present study we examined the conceptions early elementary students have regarding the work that engineers perform. Investigating the first research question led to an examination of which images students selected or did not select as being associated with engineering, which resulted in three sets, or clusters, of images being identified as *Engineering A, Engineering B,* or *Not engineering*. Further exploration of the two engineering clusters uncovered that early elementary students may have two different types of understanding of engineering. Specifically, the dendrogram illuminated two potential groups, which suggests that students make sense of engineering in two ways. These two groups associate engineering as (a) something that involves thinking, writing, or analyzing, such that engineers create designs or collect and analyze data, and (b) something that utilizes equipment (i.e., tools, machines, and instruments), such that engineers build or improve things using equipment. Additionally, the *Engineering A* cluster of the dendrogram also included images displaying collaboration between two or more people ("work as a team" and "design things"), perhaps suggesting that students conceptualize engineers as working with a team in addition to working alone. Both of these ways of thinking about engineering appear in previous research regarding students' conceptions, with the more common initial conceptions being that engineers build and improve things using equipment [5,26,30], whereas the conception that engineers engage in design processes typically occurs after an engineering session or unit [28,31].

In exploring the second research question about whether the students' associations with engineering varied across grade levels, the data suggested that the following images were significantly different between grades one and two as well as between grades one and three: "design ways to clean water", "read about inventions", and "arrange flowers". Because a larger percentage of first graders associated these images as engineering than second and third graders, we wonder if this may be illuminating a space where a shift occurs in students' understanding of engineering. Previous research has suggested that elementary students more typically focus on what engineers use (e.g., the tools) compared to upper elementary students, who were more likely to consider what engineers do (e.g., design-oriented tasks) [6]. However, our findings suggest that when given options younger students were more likely to label the tasks as engineering. This seems to align with Piaget's stages of cognitive development. Piaget believed that intelligence is something that grows and develops through the following series of stages: sensorimotor, preoperational, concrete operational, and formal operational [38]. Children in the preoperational stage are typically two- through seven-years-old. During this time their thinking is based on intuition and still not completely logical. The concrete operational stage typically occurs between the ages of seven through eleven. It is during the concrete operational stage where children begin to show logical, concrete reasoning and become increasingly aware of external events. Piaget acknowledged that some children may pass through the stages at different ages; perhaps many of the first graders in this study have not yet developed the capacity to logically select tasks that involve engineering, making their selections more inclusive.

A comparison of the images that female and male students associated as engineering was completed to answer the third research question. The results concluded that there was no significant difference based on gender. In other words, female and male students had similar conceptions of engineering in grades one–three. In early elementary grades students engage in many of the same formal and informal learning experiences; therefore, it would make sense that they might have similar conceptions. Additionally, while there were no differences between students' conceptions of engineering based on gender, the authors wonder if there may be a noticeable difference in middle school or high school, when students begin to differentiate their extracurricular experiences more (e.g., female/male sports, robotics clubs, dance, etc.).

The last research question was to investigate if there were differences between the current snapshot of data and the findings from 2005. A comparison of the current study with Cunningham et al. [29] demonstrated differences, and perhaps shifts, in the ways

that early elementary students perceive engineering today compared to those of almost 15 years ago. Specifically, the decrease in the number of students that selected pictures (i.e., "set up factories", "construct buildings", "drive machines", "install wiring", and "repair cars") where engineering is portrayed as using equipment to improve or build things was interesting, particularly with the increase in students selecting images (i.e., "design ways to clean water", "work as a team", and "design things") where engineering is showcased as designing and sometimes working as a team. These results suggest that there may have been a shift in the conceptions of students, specifically from thinking about engineering as the items or equipment an engineer uses or how they build and improve things with equipment to being more aware of the engineering design process and the teamwork associated with being an engineer. It is important to note that both of these studies offer a snapshot of data, and that this is only one comparison.

At this time it is unclear if these are just individual sample differences, if there is a connection, or if there is a shift occurring in elementary students' conceptions of engineering. These differences could be attributed to a variety of factors, including the geographic location of each sample population, grade-level sample sizes, and current events the students connect to engineering. For example, the Cunningham et al. [29] study occurred in the northeast of the U.S., while the current study occurred in the southeastern portion of the U.S. Furthermore, the SCCT framework [14] highlights that learning experiences, personal inputs (i.e., gender, grade level, and race), and background contextual affordances (i.e., parental support and role models) develop students' conceptions. According to constructivism, it is through learning experiences that students use their prior knowledge to make sense of and develop conceptions of engineering and the work that engineers do. Continued exposure to activities that involve engineering will continue to refine students' conceptions about the work that engineers do. This, in turn, could aid an individual to develop perceptions about his/her engineering abilities (self-efficacy), expected results of their actions if he/she pursues activities that involve engineering (outcome expectations), and perceived interest in the field, which could then guide one's personal goals and choice actions to pursue a career in engineering. Potential future studies could include interviews following the survey in order to gather information about why students select each image as engineering. This additional narrative may provide insights into students' conceptions about engineering and the learning experiences that developed these conceptions. In particular, it would be helpful to learn about which formal and informal learning experiences focus on building and improving things with tools compared to learning experiences that might be developing conceptions about engineering that focus on design-oriented work. According to the SCCT framework [14], continuing research of this nature (understanding formal and informal learning experiences that lead to students' conceptions) will allow researchers to better understand the foundational underpinnings of why students decide to pursue or not pursue STEM careers.

Limitations

While the Cunningham et al. [29] instrument had been utilized in a previous study, we noticed during our analysis that some of the vocabulary used in the instrument surpasses grade-level reading and would likely make younger students rely solely on the images to make a selection. Specifically, words such as "inventions, supervise, and construction" would be very difficult for first graders to read. While the images were utilized to help communicate the item choices, we also noticed while analyzing the data that some of the images selected to represent an item description did not always portray their full meaning. For example, the nature scene image for "design ways to clean water" portrays water in nature but does not provide insight into designing solutions for cleaning the water. It is not clear to what degree the images or descriptions influenced students' decisions or if students were interpreting the images and descriptions similarly. Future studies may decide to address this limitation by interviewing students or having some students complete the

survey as a "think aloud" in various grades to learn more about how students make sense of each item.

It is important to note that the original Cunningham et al. [29] instrument included a question where students could elaborate on their idea of engineering by completing the statement "An engineer is somebody who _____ ". While the decision to omit this written section seemed reasonable for this larger study, this adjustment was a limiting factor in terms of understanding students' ideas behind why they selected certain images in the survey. Additional narratives may have highlighted particular verbs, images, people, or life experiences that influenced the students' conceptions about engineering. In particular, we still wonder if students made any connections to their science classrooms or assignments. We encourage future studies to gather more data in an effort to understand students' rationales behind why they selected certain tasks more or less frequently. This understanding could potentially highlight some connection to the NGSS standards or could provide an understanding of geographical differences, cultural differences, or other experiences that students have that could impact the selection of which tasks are considered as engineering.

5. Conclusions

Overall, this study provides insights into how early elementary students identified images situated as (a) creating designs or collecting and analyzing data, and (b) using equipment (i.e., tools, machinery, and instruments) to build and improve things to be descriptive of what an engineer does for a career. These findings offer a baseline of data, after the state adopted science and engineering standards, which was compared to previous data but that could also be compared to other regions and populations. A limitation of the study is that it does not address what learning experiences lead to these conceptions of engineering, or, more specifically, what formal and informal experiences lead to each of the two ways of thinking about engineering. By adding a narrative section back into the student survey, and also by collecting survey or interview data from students, teachers, and parents, the data may triangulate, providing evidence of strengths as well as areas for improvement in formal and informal learning experiences for early elementary students. The strengths could then be celebrated and shared with others who are looking to improve students' STEM experiences, and stakeholders (e.g., teachers, administrators, STEM professionals, engineering corporations, state departments of education, etc.) might be able to offer support in the form of resources, speakers, financial donations, etc., to further support students' experiences. After all, it is by investigating students' conceptions and the ways in which these ideas are constructed, possibly by educational experiences, that we can make informed decisions about how to best support efforts to increase the STEM, and specifically engineering, pipeline of the future.

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