Abstract

An instrument designed to measure elementary school students’ knowledge of the work of engineers, as well as naïve conceptions about engineering, is analyzed. Preliminary data are presented showing the reliability and validity of scales constructed from survey items. Results from a sample of 1126 students prior to participation in engineering lessons gives an indication of students’ conceptions of engineering, and are compared to results drawn from a sample of 63 practicing and retired engineers. Findings indicate that children think of engineers as people who repair or install things like cars, computers, cable TV, and wiring; people who work on infrastructure (whether making plans or nailing shingles on roofs); and people who work with high-tech or electronic items (whether designing or operating them). Children do not believe that engineers work on simple non-electric technologies like bubble gum or bandages, or on the environment, even in cases involving invention, improvement, and design.
Introduction

In this paper, we present an instrument designed to measure children’s perceptions of what engineering work entails. Very little work has been done to examine young students’ perceptions of engineering, though interest in elementary school engineering has grown significantly. Recently, there have been calls from leaders in education, engineering, and industry for more emphasis on STEM (Science, Technology, Engineering, Math) subjects in public K-12 schools, yet the “E” is said to remain silent in most efforts—engineering remains to be significantly addressed (Lindberg, Pinelli, & Batterson, 2008; National Academy of Engineering, 2010).

This study grew from previous studies by Engineering is Elementary (EiE) that used similar instruments to examine student’s conceptions and misconceptions about engineering (Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Lachapelle & Cunningham 2007) as well as cognitive interviews conducted with children in grades 1-5 probing their understanding of engineering and what engineers do for their jobs. The results of the original analyses and the interviews informed two more cycles of modification and re-validation of the instrument over several years. The current instrument, described in this paper, is the “What is Engineering?” instrument. It includes 58 items meant to assess both children’s conceptions of engineering as a job and their ideas about what kinds of work are important in engineering.

Our goal for this paper is to address the following questions:
1. How well does the “What is Engineering?” instrument work to characterize children’s conceptions of engineering? How reliable and valid are the instrument and subscales?
2. What does this instrument reveal about children’s conceptions of engineering as compared to those of trained engineers?

Literature Review

Children’s ideas about engineers are limited. When they have any idea what an engineer might be, younger students tend to think of train engineers, while older students think that engineers are car mechanics (repairing engines), laborers, technicians, or operators of large machines (Capobianco, Diefes-Dux, Mena, & Weller, 2001; Fralick, Kearn, Thompson, & Lyons, 2009; Knight & Cunningham, 2004). A pair of large-scale studies conducted with geographically distributed samples in the United States (Cunningham et al., 2005; Lachapelle & Cunningham, 2007) confirmed that elementary schools children think of engineers as people who repair things like cars or who construct buildings and bridges.

Adults’ conceptions of what engineering entails are similarly limited. A Harris Poll commissioned by the American Association of Engineering Societies found that more than 60% of those polled reported that they feel they are not “well informed” about engineering or about engineers (National Academy of Engineering, 1998). A follow-up study showed that, when asked what engineers do for their work, about a quarter of Americans said they thought of engineers as “builders”, and another 27% as “designers” or “planners” (Davis & Gibbin, 2002). A study of preschool and elementary school teachers found that they also had shallow understanding of the work of engineers (Lambert, Diefes-Dux, Beck, Duncan, Oware, & Nemeth, 2007).
Study Design

The “What is Engineering?” instrument described and analyzed in this paper was developed to measure students’ changes in conceptions after participating in an EiE curriculum unit. EiE units are designed to teach students about engineering and technology by guiding them through an engineering design process as they design and evaluate their solution to a presented challenge. Every design challenge is contextualized by a story, presented in the first lesson, about a child who solves the same or a similar problem through engineering. Each EiE unit presents a challenge which involves the application of science in solving it; EiE units are designed to be taught in conjunction with related inquiry science units such as science units from the Full Option Science System (FOSS) curriculum.

Data for this analysis were collected from two districts in Minnesota, one urban and one suburban. Surveys were collected from students in grades 3 and 4, before they participated in EiE: all analyses, therefore, discuss students’ naïve conceptions, before participating in engineering lessons. Data were also collected from a sample of engineers.

Items were brainstormed to provide a variety of possible choices for each of the typical student conceptions we found in our earlier analyses of pencil-and-paper items, open-ended responses, and interviews: (1) an engineer constructs / makes / builds—particularly large buildings and bridges—by driving and using machines and tools; (2) an engineer fixes / repairs—especially motors, engines, or cars; (3) An engineer invents / designs / improves; (4) an engineer is anyone who works with electronics—usually by putting them together; and (5) an engineer fixes / repairs—especially electronic devices (Cunningham et al., 2005; Lachapelle & Cunningham, 2007). Items were validated through cognitive interviews with children in the target age range.

The instrument consists of 58 items. Thirty-seven items are listed under the question “Are these things that an engineer would do for his or her job?” For each of these 37 items, students are given the choice of answering “Yes” or “No”. The remaining 21 items are listed under the question, “How important are each of the following activities to the work of an engineer?” For these items, students are prompted to choose a number between 0 and 4, with 0 labeled “Not Important” and 4 labeled “Very Important”.

Results

Sample

The “What is Engineering?” instrument was used to assess 1126 students in the public school systems of two Minnesota school districts, one large and urban and the other smaller and suburban. These students were enrolled in grades 3 and 4. Of the students reporting their gender (n=1113), 577 (51.8%) were female and 536 (48.2%) were male. A sample of engineers (n=63) also completed the “What is Engineering?” instrument. Of the sample, 23 (36.5%) of the respondents were female and 40 (63.5%) were male. The engineers have an average of 12.11 years of experience in engineering, with half having 8 or more years of experience (32 respondents, 50.8%).
Factor Analysis, Scale Construction, and Means: Binary “Job” Items

The purpose of the first section of the “What is Engineering?” instrument, which asks “Are these things that an engineer would do for his or her job?”, is to explore children’s conceptions of what sorts of work “count” as engineering. Participants were presented with descriptions of 37 work responsibilities and asked to answer “Yes” or “No”. Figure 1 depicts the individual items and what percentage of students selected each as part of an engineer’s job; for comparison, the percent of engineers selecting each item is also presented.

Figure 1: Students’ and Engineers’ Choices of What an Engineer Would Do for His/Her Job
For each item in the survey, student responses were converted from “Yes” or “No” to scores of 1 or 0, respectively. These scores were summed, and the resulting overall score analyzed for internal-consistency reliability. Reliability measured was acceptable (Cronbach’s $\alpha = .881$).

An exploratory factor analysis, conducted as a principal components analysis (PCA) with oblimin rotation was performed in SPSS to explore the underlying patterns within students’ item choices. This exploratory factor analysis identified seven components accounting for 49.37% of the variance. Bartlett’s Test of Sphericity ($p<.000$) and the KMO Measure of Sampling Adequacy (KMO = .898) both indicated high factorability. Examination of the scree plot confirmed the importance of the seven components which were extracted with eigenvalues greater than 1.0. The scales constructed from these components can be classified as Work with Electronics, Construction, Driving, Non-Electronic Design (design of items that are not electronic), Work with the Environment, Repairing/Installing, and Industrial/Commerce. One item (15) did not fit with any scales. The specific items comprising each of these scales, as well as scale descriptives, are shown in Table 1. Table 2 shows differences in means and standard deviations for student and engineer responses as summed for each of the scales.

| Table 1: Scale Descriptives for Items 1-37 “Things an engineer would do for his/her job” |
|-----------------------------------------------|------------|----------|-----------------|
| Scale                                         | Items      | Scale Range | Cronbach’s $\alpha$ |
| A. Work with Electronics                       | 5, 12, 16, 18, 24, 30 | 0-6       | .717             |
| B. Driving                                     | 2, 7, 10, 14, 22, 31  | 0-6       | .741             |
| C. Construction                                | 8, 20, 28, 32, 33, 34, 35 | 0-7   | .728             |
| D. Non-Electronic Design                       | 1, 4, 9, 11, 13     | 0-5       | .734             |
| E. Work with Environment                       | 16, 17, 21, 23, 27  | 0-5       | .730             |
| F. Repairing/Installing                        | 3, 6, 19, 25, 26, 37 | 0-6       | .717             |
| G. Industrial/Commerce                         | 22, 29, 32, 36      | 0-4       | .608             |

| Table 2: Scale Means and Standard Deviations for “Things an engineer would do for his/her job” |
|-----------------------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| Scale                                         | Student Responses | Engineer Responses | Student Responses | Engineer Responses | Student Responses | Engineer Responses | Student Responses | Engineer Responses | Student Responses | Engineer Responses | Student Responses | Engineer Responses |
| A. Work with Electronics                       | 0-6 3.42 1.891    | 0-6 4-6 5.32 0.506 |
| B. Driving                                     | 0-6 1.71 1.779    | 0-3 0.26 0.613     |
| C. Construction                                | 0-7 3.76 2.125    | 0-5 3-5 3.09 0.506 |
| D. Non-Electronic Design                       | 0-5 1.67 1.623    | 0-3 5-4.88 0.375   |
| E. Work with Environment                       | 0-5 2.56 1.723    | 0-3 5-4.88 0.378   |
| F. Repairing/Installing                        | 0-6 3.92 1.819    | 0-5 1-1.10 1.249   |
| G. Industrial/Commerce                         | 0-4 1.57 1.306    | 0-1 0.07 0.260     |

Factor Analysis, Scale Construction, and Means: Scaled “Importance” Items

To further explore children’s conceptions of engineering and related careers, the second section of the assessment asked participants to consider 21 activities and to indicate “How important are each of the following activities to the work of an engineer?” Students could respond on a five point scale, ranging from 0 (Not Important) to 4 (Important). Figure 2 shows the individual items and the ratings reported by participants—both students and engineers.
As above, an exploratory factor analysis of these items was undertaken in SPSS to examine any underlying patterns within students’ responses. We ran a PCA with oblimin rotation, and checked for internal consistency reliability. Reliability of this full sample of questions was acceptable (Cronbach’s $\alpha = .871$). Bartlett’s Test of Sphericity ($p<.000$) and the KMO Measure of Sampling Adequacy (KMO = .913) both indicated high factorability. The analysis identified four components accounting for 49.64% of the variance. Two of these factors included 17 of the 21 items; inspection showed that one of the two
factors consisted of items that could be interpreted as “Important to Engineering” and the other of items “Not Important to Engineering”. The remaining two factors were difficult to interpret. PCA was run on the “Important to Engineering” items, plus two of the remaining items (55 & 58); this analysis showed two sub-factors for the “Important to Engineering” scale, interpreted as the scales “Using ideas, math, science, creativity, and models” and “Communicating with Others” (Table 3). Running PCA on the “Not Important to Engineering” scale with item 57 resulted in only one factor (Table 3). Item 57 was dropped at this point as it did not load onto any factors. Characteristics of the constructed scales and sub-scales, with the specific items comprising each scale are shown in Table 3.

Table 4 shows means and standard deviations for the engineer and student samples for each scale and subscale. Engineers rated the “Important to Engineering” scale and subscales much more highly than students, and gave a lower mean rating to the “Not Important to Engineering” scale. Also, students’ scores spanned the whole possible range for each scale, while engineers clustered much more tightly towards the top or bottom.

To further investigate the students’ conceptions of engineering, we made a scatterplot of students’ “Important to Engineering” and “Not Important to Engineering” scores graphed against each other. This showed a strong tendency for students to rate everything highly (see Figure 3), with fewer students in the corners where they rated one scale highly but not the other, or near zero where all items were given low ratings. For comparison, our sample of engineers clustered in the bottom right, showing that nearly all gave high ratings to “Important…” items and low ratings to “Not Important to Engineering” items (Figure 4).
Figure 3: Scatterplot of “Important to Engineering” vs. “Not Important…” Scores per Student

Figure 4: Scatterplot of “Important to Engineering” vs. “Not Important…” Scores per Engineer
Discussion

Binary “Job” Items

As expected from earlier research, elementary school students were much 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 electronic or having to do with cars. Rather than focusing on the “verb”, students often appear to focus on the “noun” of each task: what it is that is being worked on, rather than what sort of work is being done.

Our factor analysis of items showed strong factoring into theoretically interpretable factors. We also found that our identified factors roughly corresponded with the conceptions of engineering that we found in our earlier research. As expected, we found a factor for “construction” items, corresponding with our earlier findings discussed above that (1) an engineer constructs / makes / builds—particularly large buildings and bridges—by driving and using machines and tools. This factor, as derived from student responses, included both engineering (e.g. “Figure out how tall you can safely build towers”) and non-engineering (e.g. “Nail beams together for new houses”) responses. Unlike the engineers, elementary school students did not, as a rule, distinguish between these kinds of construction activities.

We also found a factor for “Repairing & Installing”, matching our earlier findings that students believe that (2) an engineer fixes / repairs—especially motors, engines, or cars; and (5) an engineer fixes / repairs—especially electronic devices. Students were much more likely than engineers to choose items composing this scale (Mean of 3.92 for students, 1.10 for engineers). Corresponding to our earlier finding that students believe that (4) an engineer is anyone who works with electronics—usually by putting them together, we found a factor for “Working with Electronics”. This factor includes mostly examples of engineering work (e.g. “Design smaller kinds of computers”) with the exception of “Run machines for doctors and scientists”, which our sample of engineers found ambiguous.

Our factor “Non-Electronic Design” corresponds with our earlier identified conception that (3) An engineer invents / designs / improves. Engineers consistently chose the items composing this scale (mean=4.88 out of 5 possible) while students rarely chose them (mean=1.67), reflecting students’ more naïve ideas about what engineers do—they tended to avoid items mentioning simple, non-electrical technologies like bubble gum. Three final factors did not correspond to any earlier findings; all were comprised of items that students were less likely, as a rule, to choose. These included “Driving” items, all of which described non-engineering work (engineers’ mean=0.26 out of 6), “Environment” items, all of which were examples of engineering (engineers’ mean=4.88 out of 5), and “Industrial/Commerce” items, none of which were examples of engineering (engineers’ mean=0.07 out of 4).

Scaled “Importance” Items

Both the scatterplot and bar graph show that engineers are much more clear and consistent than elementary students in rating the importance of different activities in engineering. Unlike engineers, students were likely to rate everything “Very important” or nearly so: only two items were given such
high ratings by fewer than half of students (“Driving machines” and “Driving people from place to place”). This indicates that few students had any clear idea of what activities are important in engineering. However, the existence of reliable and well-defined factors for activities “Important to Engineering” and “Not Important to Engineering” in the analysis of student data indicates that this instrument will be able to differentiate between those students who have a clear understanding of what engineers do and those who do not.

Conclusions

In this paper we have presented a survey instrument with reliable, clearly delineated scales which correspond to earlier findings of students’ naïve conceptions about engineers and engineering. This instrument has the potential to distinguish students with clear conceptions about engineering from those who do not, as well as to identify students with particular naïve conceptions. It can be used to test the efficacy of engineering lessons and curricula in correcting misconceptions, as well as to identify naïve conceptions present in a tested population.

Further work is needed to identify items which can be dropped without reducing the efficacy of the instrument. This instrument should also be tested with students who have participated in lessons designed to help them learn about engineering, to see if factors break down differently in such a population. Also, further work is needed to identify “cut scores” for students with likely misconceptions. Confirmatory factor analysis with data drawn from a new population would help to confirm that the instrument can contribute to a coherent model of students’ conceptions and naïve conceptions about engineers and engineering.

References


