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Sixth-Grade Students' Views of the Nature of Engineering and Images of Engineers

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Abstract This study investigated the views of the nature of engineering held by 6th-grade students to provide a baseline upon which activities or curriculum materials might be developed to introduce middle-school students to the work of engineers and the process of engineering design. A phenomenographic framework was used to guide the analysis of data collected from: (1) a series of 20 semi-structured interviews with 6th-grade students, (2) drawings created by these students of "an engineer or engineers at work" that were discussed during the interviews, and (3) field notes collected by the researchers during the interviews. The 6th-grade students tended to believe that engineers were individuals who make or build products, although some students understood the role of engineers in the design or planning of products, and, to a lesser extent in testing products to ensure that they "work" and/or are safe to use. The combination of drawings of "engineers or engineering at work" and individual interviews provided more insight into the students' views of the nature of engineering than either source of data would have offered on its own. Analysis of the data suggested that the students' concepts of engineers and engineering were fragile, or unstable, and likely to change within the time frame of the interview.

Keywords 6th-Grade students · Engineering design · Engineers-at-work drawings · Middle-school students · The nature of engineering · Phenomenography

Introduction

It has been more than 25 years since a "Science for All" movement was initiated (National Science Foundation 1983; The Royal Society 1985; UNESCO 1983) whose goal was to put science education for all students on an equal footing with the traditional goal of preparing future scientists (Fensham and Harlen 1999). This movement eventually led to the acceptance of scientific literacy as one of the main goals of science education at the K-12 level (deBoer 2000; Hurd 1998), and the recognition in documents such as "Science for All Americans" (American Association for the Advancement of Science 1989), "Benchmarks for Scientific Literacy" (American Association for the Advancement of Science 1993), and the "Inquiry and the National Science Standards" (National Research Council 2000) that an understanding of the nature of science (NOS) is one of the central components of scientific literacy.

An outgrowth of the call for scientific literacy was the Science, Technology, and Society (STS) movement (Yager 1996), which called for teaching science within its technological and societal context. The STS movement led to the creation of curriculum materials that provided students with a perspective on the human and social aspects of

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science (Aikenhead 2005; Mansour 2009; Yager 1996), as well as studies that probed students' views of STS at all levels (e.g., Bradford et al. 1995; Fleming 1988; Kaya et al. 2009; Rubba and Harkness 1993; Yalvac et al. 2007), and special survey instruments such as the VOSTS (Aikenhead and Ryan 1992; Ryan and Aikenhead 1992) to study students' views of the social nature of science, how society influences science and technology, how the way science is taught influences society, and so on. The STS perspective, however, still placed greater emphasis on science than technology or engineering. As a result, specific definitions and benchmarks for technological literacy were not well documented until recently (Hall 2001).

Recently, a movement has begun that calls for technology literacy for all Americans to serve as a base for understanding the capabilities, power, and effects of technology (International Technology Education Association (ITEA) 1996, 2006, 2007). The International Technology Education Association (ITEA) has suggested that an understanding of the nature of science and technology can provide the basis upon which today's civilized societies make more responsible and more rational informed decisions about the development and implementation of new technologies and evaluate the effects of technology on the environment and society (ITEA 2007).

Research has shown that students' ideas and beliefs about the NOS have an effect on their learning of the content of science (Ryder et al. 1999; Sadler et al. 2004). It has also shown that having an informed view of the NOS can improve students' attitudes toward science, help them internalize science, and eventually enhance their scientific knowledge (Finson 2002; McComas et al. 1998). It is therefore reasonable to suggest that an improved understanding of the nature of engineering (NOE) could lead to useful learning outcomes within the fields of engineering and technology. The International Technology Education Association (ITEA 2007) has asserted that an increasing knowledge of engineering may increase the number of students who choose engineering and technology as their future career. It could also have an effect on how students undergo the transition from students to practicing engineers after graduation (Robinson and Kenny 2003).

Carroll (1997) has shown that high-school students' attitudes toward engineering become more favorable as their knowledge of engineering increases. Although recent data have demonstrated a slight increase in engineering enrollment (Gibbson 2009), a further increase in enrollment rates is crucial because it has been suggested that the need for engineering and technology-related graduates is higher than ever (Grose 2006).

There has been a growing interest in integrating engineering into the K-12 curriculum as a result of the perceived demand for engineers and technicians (Cunningham et al. 2005; ITEA 2007; Lyons and Thompson 2006), but the question of how to achieve this increased interest is still debatable. There have been relatively few studies, however, of students views of engineers and the nature of engineering at the K-12 level that might help shape the integration of engineering content into the middle-school and high-school curriculum (Cunningham et al. 2005; Fralick et al. 2009; Knight and Cunningham 2004; Lyons and Thompson 2006; Oware et al. 2007; Thompson and Lyons 2008). We have therefore undertaken an in-depth study of 6th-grade students' perceptions of engineers and the nature of engineering.

Views of the Nature of Science and Engineering

The Nature of Science (NOS)

According to McComas et al. (1998) the nature of science (NOS) is a comprehensive concept derived from a variety of issues related to the philosophy, sociology, and history of science. The NOS has been defined as part of the epistemology of science, describing science as a way of knowing, or of values, beliefs and assumptions inherent to the development of scientific knowledge (Abd-El-Khalick et al. 1998; Bell et al. 2000; Lederman 1992).

Lederman et al. (2002) have argued that there is a "shared wisdom" about certain aspects of the NOS among diverse groups of professionals including science educators and practitioners of the fields of philosophy, history and sociology of science. They argued that "… scientific knowledge is tentative; empirical; theory-laden; partly the product of human inference, imagination and creativity; and socially and culturally embedded." They also noted that there is general agreement about the difference between observation and inference in science, and that there is no recipe-like method for doing science.

Research on individual's views of the NOS has suggested that students, teachers, and the vast majority of members of society, in general, believe certain common myths about science that include the myth that scientific facts are absolute and purely objective; that there is no role for human interpretation or imagination in science; and that scientists have certain rigid methods to generate scientific knowledge and/or solve problems (Abd-El-Khalick et al. 1998; Irez 2006; McComas 1997; Palmquist and Finley 1997; Stein and McRobbie 1997).

Driver et al. (1996) have shown that students form ideas about science, its process, and its product—scientific knowledge—before they receive any formal instruction in science. Even elementary school students have been shown to have ideas about how scientists work that come from their exposure to the images of science and scientists from a variety of sources, including films, textbooks, television programs, and from their parents and relatives (Driver et al. 1996; McComas 1998). Inasmuch as we live in a world in which engineering artifacts surround us, even middle-school students should possess elements of a developing epistemology of engineering. This study was therefore based on the assumption that investigating 6th-grade students' views of the nature of engineering (NOE) could provide a baseline for efforts to prepare professional development workshops for teachers interested in implementing aspects of engineering into their classrooms and for the development of curriculum material for use with students at this level.

The Nature of Engineering

Unlike the well-established field of the philosophy of science, relatively little progress has been made toward consensus on one or more philosophies of engineering (Koen 2003; Mitcham 1998). Ihde (2004) has claimed that philosophy of technology has not constructed "recognizable and sustained internal arguments" (p. 124), and that the philosophy of technology is more "pre-paradigmatic" than the philosophy of science.

Various elements that could become part of a model of the nature of engineering, however, can be extracted from the literature. Engineering solutions are tentative (Koen 2003); involve designing artifacts and systems (Bucciarelli 2003; Dym et al. 2005; Lewin 1983; Vincenti 1990; Wulf 2002); depend on existing scientific and mathematical theories as well as failures and successes in the field (Adams 2004); are affected by cultural norms and the needs of society (Adams 2004; Dym 1999; Dym et al. 2005); involve stepwise iterative and collaborative problem-solving activities (Bucciarelli 2003; Dym 1994; Koen 2003; Vincenti 1990); require creativity, imagination, and the ability to integrate different scientific, mathematical and social values and theories in novel ways (Adams 2004; Rogers 1983); are the result of a complex human endeavor that requires analytical thinking to make complex problems simpler (Dym et al. 2005; Koen 2003; Matthews 1998); and are an holistic, open-system approach that requires considering all aspects and perspectives of not only artifacts and costumers, but also its effects on the environment, individuals and society, and culture (Adams 2004; Mitcham 1998; Rophl 2002).

Methodology

The goal of this study was to investigate 6th-grade students' views of engineers and the nature of engineering, and to probe the experiences that may have shaped these students' perceptions of engineering. The study was based on the following guiding research questions:

- What are 6th-grade students' views of the nature of engineers and engineering?
- How do 6th-grade students differentiate between engineering and science?

In order to address these research questions we probed the images of engineering that 6th-grade students hold, what these students think engineers do, and ways in which these students think engineering affects their lives. We also tried to get them to distinguish between science and engineering.

Theoretical Framework

The design and execution of this study were guided by the theoretical framework known as phenomenography (Marton 1986, 1994), which needs to be differentiated from a philosophical perspective known as phenomenology (Marton 1996). *Phenomenology* involves the study of the world as we experience it (Sokolowski 2000; van Manen 1990). As noted elsewhere (Bodner 2004), "phenomenology searches for the 'essence' of a phenomenon, the 'something' that makes the phenomenon what it is, the 'something' without which the phenomenon could not be what it is." Paraphrasing van Manen (1990), one might use a phenomenological framework to search for an understanding of the "essence" of the experience of being a father that all fathers might share.

The focus of *phenomenography* is still on the meaning of an experience, but this theoretical framework assumes that people can and will experience the same phenomenon in a limited number of ways that are qualitatively different (Säljö 1997). The goal of phenomenography is to define the different ways in which individuals experience, interpret, understand, perceive, and conceptualize a given phenomenon, or aspect of reality (Marton 1986), which in this case would be the field of engineering.

The result of phenomenographic research is a set of categories of description of various aspects of the individuals' experiences of the phenomenon. Phenomenographic research involves identifying conceptions of the phenomenon and then looking for underlying meanings and relationships among these different conceptions (Orgill 2007). Marton (1981) captures the essence of phenomenography by noting that it searches for the middle-ground between the extremes of "the common" and "the idiosyncratic." Phenomenography was deemed appropriate for this study because it allowed us to investigate similarities and differences in the perception of engineering that 6th-grade students constructed as a result of their experiences.

Setting and Participants

Two middle schools from a small Midwest town were selected for this study. The main considerations in the selection process were to have school districts that were close to the national average in terms of the intellectual levels of the inhabitants, and that were unlikely to be influenced by the presence of a concentrated community of practicing engineers or a School or College of Engineering. The schools from which students were selected were 30 miles from the closest university.

As shown in Table 1, a total of 370 students were enrolled in 6th grade in these schools. The participants in this study were a sample of 20 Caucasian 6th-grade students who were 11–12 years old. An equal number of male and female students were purposefully selected from the students who volunteered to participate in the study. The only criterion in the selection process was the students' gender. Neither ethnicity nor economic status was part of the selection process because of the ethnic homogeneity among the volunteers. The demographic data in Table 1 suggest that the two schools were similar in terms of size, ethnicity, and reasonably similar in socio-economic status.

Data Collection and Analysis

A primary source of data for this study was a series of interviews with 20 6th-grade students that averaged approximately 45 min in length, with a range of between 35 and 70 min. The interviews followed a semi-structured format based on a pre-determined interview protocol. The interviews were conducted by the first and second authors of this paper, working as a team, and transcribed verbatim. Codes were assigned to each student and to the two researchers for use in presenting quotes from the interviews. The code F17, for example, represents a female student with the assigned number of participant 17. The two researchers involved in the interview are represented as R1 and R2.

During the interviews, the students were shown a variety of pictures associated with a product or artifact of the engineering process, such as a roller-coaster, a highway overpass, one of the space shuttles, different generations of MP3 players or videogame consoles, and a car.

This was done to provide a context for the interview questions, inasmuch as an earlier study of the NOS demonstrated that more insightful answers to epistemological questions can be obtained by putting these questions into the context of the individuals' experiences (Samarapungavan et al. 2006), The students were asked to think about the engineers who contributed to these products being available. At the point in the interview where the discussion focused on the MP3 players and videogame consoles, the students were asked about the process by which these products changed—what engineers would refer to as the design process. During the discussion of the photograph of a car, they were asked to explain what part or parts were "engineered." During the interviews, the students were asked to define the term *engineering*, to explain its role in society, and to differentiate engineering from science.

Each student was also asked to draw "an engineer or engineers at work" and then talk about their drawing during the interview. The drawings were included in the interview protocol because of prior work that suggested that drawings might provide a broader picture of the thought process of 6th-grade students (White and Gunstone 1992).

The interview transcripts were combined with the artifacts generated when the students were asked to draw an engineer as the basis of a phenomenographic analysis that sought to identify qualitatively distinct categories or clusters of students' experiences of the phenomenon of engineering. The analysis began with open coding based on a grounded-theory approach (Strauss and Corbin 1990) as a form of inductive analysis (Patton 2002).

The first level of analysis involved having the researchers who had participated in the interviews independently examine a subset of one-quarter ($n = 5$) of the transcripts of the student interviews to create a series of initial codes based on similarities and differences in the responses. The researchers then discussed their initial codes and possible categories that might emerge from the codes. The data were then subjected to a second and deeper analysis that helped the researchers develop categories that were more general. One of the goals of this process was developing internal consistency within each category. Another important goal was the development of as few general categories as were needed to describe all of the participants' views. After the first set of categories had been developed from an analysis of five interview subjects, the remaining data were examined to look for additional categories of description.

The students' "draw an engineer" drawings were analyzed using a modified version of the rubric developed by Fralick et al. (2009) that involved the categories of

Table 1 Demographics of the schools selected for the study

	Enrollment		Ethnicity (%)			Socio-economic data (%)	
	6th Grade	Total	African–American	Hispanic	Caucasian	Free lunch	Reduced lunch
School 1	180	550	N/A	1	99	16	12
School 2	190	590	2	8	89	35	10

appearance, *objects*, *actions of engineers*, and *locations*. Each drawing was examined within the context of the transcript of the part of the interview during which the students were asked to describe or explain what they drew. When a student drew an engineer who appeared to be just standing, for example, we checked the interview data to distinguish whether the engineer was described by the student as doing or making something rather than just standing and whether the student described the engineer as male or a female.

Results

Results Obtained From Drawings

All but one of the twenty participants in this study completed the drawing task. The participant who chose not to complete this task noted that she felt she did not have adequate drawing skill. Many of the other students stated that they were not good artists, and therefore preferred drawing people as stick figures. On the basis of the participant's description of the drawing during the interview, we coded 13 of the engineers as males, one as female, and six as having an unknown gender. Other characteristics coded within the category of appearance were two examples of engineers dressed in laborer's clothes, two examples of engineers wearing a cap or hat, one example of the use of a hard hat, and one example of an engineer drawn wearing glasses.

Within the category of objects we coded examples of 17 different types of objects that were drawn a total of 58 times. This category included nine examples of people who were not engineers working with the engineers. Seven of the drawings included blueprints, sketches, or plans for building or making something. Other popular objects included furniture (especially tables) (7), passenger vehicles (5), computers (4), tools for building or fixing an object (4), writing materials (4), high-tech or electronic products (3), other machines (3), buildings or other civil structures (2), indications of individuals "thinking" (2), lamps (2), control panels or remote control devices (2), and one example each of a robot, a factory assembly line, construction vehicles, and a train on tracks.

Nine examples were found within the category of ways of depicting the actions of engineers that involved designing, inventing, creating, or planning a product. Another nine examples portrayed engineers involved in making, fixing, or working on an object with their hands. Operating or driving machines or vehicles were noticed in four students' drawings. Some of the other, less frequently noticed, actions of engineers were doing experiments and testing products (3), working on computers (3), explaining or teaching (2), designing, decorating and painting (2), looking for errors (1), and assembling a car (1). More than half of the drawings included some aspects of the process of engineering, but these drawings also contained examples of individuals labeled as "engineers" involved in actions that are not related to being an engineer, such as operating a crane or assembling a product.

The last category for which we coded the drawings indicated the location in which the engineers worked. Most of the drawings suggested that engineers work indoors, in offices or garages. Three of the drawings were coded as being examples of engineering work being done outdoors, and the locations for four of the drawings were not clear.

Results Obtained From Interviews

The researchers agreed on a set of seven categories that emerged from analysis of the interview data that could be described as follows: (1) who is involved in decisions about how a product should be created or built?; (2) what do engineers do?; (3) attribution of the work of other occupations to engineers; (4) characteristics of engineers; (5) how do engineers do what they do?; (6) effects of engineering in daily life; and (7) the difference between science and engineering.

Who is Involved in Decisions About How a Product Should be Created or Built?

The interviews began by asking students to tell us what they would like to be when they grew up. If they were not sure, we asked whether there was any job they didn't want to have. We then showed the students pictures of an amusement park, a space shuttle, and a highway overpass and asked them about the people involved in creating these objects or making decisions about how they should be built. The student responses to this question are summarized in Table 2. Note that the sum of items in each row exceeds the number of participants in the study because students often gave more than one answer.

A significant number of the students (40%) had no idea who might be involved in making decisions about how a roller-coaster should be built. Consider, for example, one student's response when asked if he had any ideas who made decisions on how to build roller coasters during a discussion of a photograph of a local amusement park.

> M01: No, but they were really, really smart cause that's a pretty good park right there.
> R1: Do you have any ideas who would make it or decide how to make it or create it?
> M01: Well, no not really. I don't have any idea

The percent responding this way decreased for the examples of the space shuttle and a highway overpass. As

Table 2 Student responses to the question of who creates the artifact

Object shown	Engineers	Architects	Workers	Scientists	Designer	I don't know
Roller-coaster	12	5	1	1	2	8
Space shuttle	14	3	–	4	1	3
Highway overpass	10	5	5	1	1	2

we will see in the analysis of other categories, the fact that students reported the involvement of engineers in creating the objects in Table 2 does not imply that these individuals were involved in what engineers would consider to be the design process. Consider the following example of a discussion of a photograph of a highway overpass.

R1: Can you guess what it is?
F17: Roads. Highways, interstates.
R1: Yeah. How much do you know about roads?
F17: I know they have to plan everything out like cause … it takes them a long time to build stuff like this.
R1: So, who helps plan it all out?
F17: Like construction workers can do this and it comes back to architects or engineers. I know architects do buildings and stuff and maybe more than with roads.
R1: Do you think architects and engineers are the same thing?
F17: Umm … I think architects build more of buildings. And engineers can do more with rollercoasters and stuff like that.
R1: What else could they do?
F17: Um, cars. Like building cars and stuff.

What do Engineers do?

One of the interview questions asked the students whether they were familiar with the terms *engineering* and *engineers*. They were then asked how they would explain their ideas about engineering and what engineers do to a friend or brother or sister. As a result, almost every participant addressed the issue of what engineers do during the interview.

All of the participants pointed out one or more artifacts that engineers either "made" or "built." They differed, however, in their description of the ways and stages in which engineers were involved in the making or building process. Three main artifacts were invoked by the students as examples of objects they believed required the assistance of engineers during the building process: vehicles and other machines ($n = 14$), structures (such as buildings) ($n = 13$), and electronic devices ($n = 3$). It should be noted that 11 of the 14 students who indicated that engineers were involved in building or making various vehicles stressed that the work engineers did involved putting the vehicle parts together, welding them or assembling them. Consider the following extract from the interview with the participant given the code F17.

F17: Engineers working on cars and stuff.
R1: What would they do with the car?
F17: I think when they're putting the car together and everything, I know factories do it now, but engineers work the machines and stuff, …
R2: Who put the seats into the car?
F17: Um, I guess engineers, 'cause I don't know.

In addition to making vehicles or machines, 13 students indicated that engineers build structures, including roads, railways, buildings, tunnels, and amusement parks. Four of the participants focused on "mega structures" and skyscrapers.

R1: … so what type of things do they build?
F19: Like the streets, um like roller-coasters, and then they can also help build like really tall towers.

Eight of the participants who indicated engineers build structures conveyed the impression that the role of engineers was that of construction workers. This was captured in the drawing shown in Fig. 1, for which the student identified as subject F19 explicitly noted in her interview that she put stars next to the stick figures in the drawing that were engineers.

R2: Can you tell me what these people are doing?
F19: They are making sure that this little like, like that's a floor and they're making sure that it's heavy enough

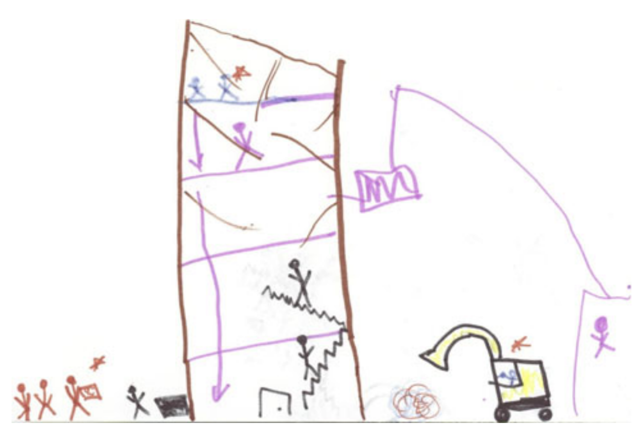

Fig. 1 A student's drawing that shows workers constructing a building. The engineers are the stick figures marked with an *asterisk*

and like people down here make sure that it's heavy enough that they wouldn't fall through. That would be bad.
R2: Okay, what I get is all of them are checking something, who is umm … building?
F19: Like he could or I first started to draw like a crane and placing onto the building.
R2: Are those also engineers?
F19: Yeah.
R2: Who operates that crane is engineer?
F19: Umm (while nodding as if saying yes). It's not a very good picture, but, oh well.

Five of the students in this study explicitly indicated that engineers are involved in the design of a structure. These students were likely to invoke a chain of command in the process of building a structure, and note that engineers are responsible for specifying how it should be built. Consider the following interaction with participant M05.

R2: What kind of engineer?
M05: A construction engineer.
R2: What do construction engineers do?
M05: They … like make the layout for the roads and the highways and like the ways you get around. … Create the things and then tell … Like create 'em in their mind then jot it down and then tell the other people to go … Like the workers … They tell the foreman and the foreman tells the workers.

Half of the students noted that engineers not only make or build things, but also fix them. Consider the discussion of the drawing shown in Fig. 2, in which the student explained what the engineer was doing in this picture.

M01: Or fix it. I think, um, like a repairman would be an engineer too, 'cause he's helping fix something, anything in a house or a car.

Almost half of the student responses also pointed out that engineers test products to check whether they function right, are built in accordance with blueprints, are safe to use, and so on. These students stressed the importance of checking whether all parts of a machine work properly and to consider safety issues when referring to roller coasters.

Fig. 2 A student's drawing used to indicate that engineers both make and fix machines

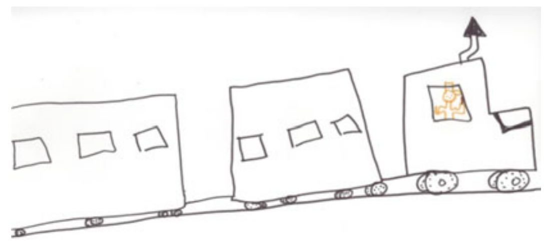

Fig. 3 A drawing that depicts the student's idea that engineers drive trains

F14: … they have to design it and make sure all the parts are right and then there are people that build it and make sure it works right.

Five students anticipated the need for an engineer to calculate or estimate how much money a project would cost, how large the product should be, how long it was going to last, or how fast something like a roller coaster can go while operating safely. Consider the following responses to the question of what engineers might do given by students M09 and F11.

M09: Umm … Design it, that design roller coaster or maybe … calculate how fast it goes or something …
F11: … they have to think about how much money it's going to cost and what supplies they need.

As shown by the example in Fig. 3, three students thought that engineers drive trains.

M01: An engineer is someone who will be able to fix things or drive things. When I think of engineering I think of someone who drives a train.

Attribution of Work of Other Occupations to Engineers

There were numerous examples in the study in which students attributed work done by a variety of professions—including architects, factory and construction workers, scientists, locomotive engineers, mechanics, and carpenters—to the domain of work done by engineers. Nine students, for example, confused the role of engineers and architects in designing buildings and other structures. One student tried to differentiate between architecture and engineering as follows:

M08: Engineering like … mostly architects design it and a lot of people that are engineers or architects are sometimes are engineers and they do both. … Engineering … they think of the new technology I guess and they design it and usually (an) architect just designs it.

A few students also assigned engineers the roles of factory or construction workers.

R1: Do you have any ideas about who made the decisions of how that [referring to a bridge] should be built?
F04: Road constructers. … because some people work on roads and the other people work on the concrete, while the other people like get the road done and then while they work on another section the other people work on pouring the concrete in. …

The students routinely confused science with engineering. One student, for example, believed that engineers try to understand the universe, whereas another claimed that Thomas Edison was a scientist because he invented the light bulb.

F18: … there are engineers that make things for people to have fun, like roller coasters and things, and there are some that want to figure out about our universe and everything. They have different ideas, but they pretty much do the same thing but not exactly in the same way.

Some students confused the work of engineers with that of mechanics and technicians involved in fixing machines or electronic equipment.

R1: What do you mean by engineers? What type of people are they?
F02: What, like? They're mechanics and stuff. They help fix it or they help put it together and stuff.

Figure 4, for example, was drawn by a student who tried to convey the image of mechanical engineers working in an auto body shop to repair cars.

M05: The guy is working on the tail of the car. That guy is painting it and working on the car in the body shop.
R2: So, those are engineers?
M05: They're mechanical engineers.

Characteristics of Engineers

Although none of the interview questions directly probed the students' views of the characteristics of a good engineer, their responses to other questions suggested that the students believed engineers had to be "smart" and that they needed practical knowledge, although there was some disagreement about whether they had to be creative. Five participants commented about the need for engineers to be smart enough to grasp the necessary knowledge and eight participants believed they had to be creative in order to come up with ideas for improving the efficiency of the products on which they worked. Two students, on the other hand, stated that creativity is not necessary to be an engineer.

Fig. 4 A student's drawing created to indicate that engineers fix cars

R1: Outside of experience do you need anything else to be an engineer?
F14: Might want to be smart, well I mean.
R1: Why do you need to be smart?
F14: I think there's a lot of math.

As noted previously, only one student (a female) drew a female engineer. The other students either explicitly drew figures for engineers that were male, used "he" in the interviews when talking about engineers, or offered no sign of gender in their drawings or their discussion of the drawings. When explicitly asked whether females could become engineers, the students agreed that this can happen, but it seemed that until that question was asked, engineering was seen as a career choice for males.

How do Engineers do What They do?

In addition to describing *what* engineers do, some of the student responses contained descriptions of the students' beliefs about *how* engineers do what they do. During the interviews, the students were shown pictures of several generations of videogame consoles (e.g., PS2 versus PS3) and told that the process by which a new generation of a game console replaces one of the older generations could be called "design." They were then asked whether they could identify other examples of design in the world in which they lived.

More than half of the students ($n = 13$) stated that the main reason for a design change was to make the product better, which prompted the researchers to probe students' beliefs about the meaning of the term *better*. One student indicated that this would involve making the product more durable, whereas five others suggested it would involve making the product smaller or thinner. Only one student mentioned environmental issues as a reason for design change, as shown in the following extract from his interview.

M01: Well, like now they're … thinking about making a solar car because our air is getting polluted and stuff and our resources are dying off, like oil.

Another reason that students cited for design change was to improve sales or market share. Two students suggested that design change occurred in order to meet the needs and demands of customers, whereas four students claimed that the primary reason for design change was to increase sales by making the product "look cool."

M20: Well, they make it because they wanted to look cool and they want more people to buy it because they make it [a] little cooler …

The students in this study proposed five things that engineers need to consider during the design process: functionality, aesthetics, safety, durability, and material selection. Five students pointed out that the product had to do its job well. Four students believed that it should also "look good" aesthetically. Six students brought up the issue of safety in terms of the product being safe for people to use. Five students focused on the importance of the durability of the product and three mentioned the appropriate selection of materials, although only one of these students explicitly addressing the issue of cost-efficiency.

M08: … [if] they design something wrong and there could be difficulty like technical difficulty and something could happen to like the car, or the road fall, like the bridge if they didn't design like the … pull or whatever right. They didn't make it wide enough then [the] road could collapse [if] there is too much weight. … They wanna make every little detail good. They don't wanna mess up.
R2: Because?
M08: They don't want anybody [to] get hurt from their design.

More than half of the students divided the process of solving engineering problems into a series of stages while explaining what engineers do. Although no individual student described all of the stages in the model of the engineering product design process developed by the Boston Museum of Science as part of their *Engineering is Elementary* Project (Boston Museum of Science n.d.), the 14 students who commented on the process of engineering, as a whole, provided responses that were consistent with each of these stages.

Step 1 *Imagination/preparation*: Six of the students stated that engineers start by thinking about ideas by either brainstorming with people or getting ideas from consumers. One student suggested that the building of a new bridge should start by examining (reverse-engineering) old ones

Step 2 *Planning*: Seven students mentioned that sketching, planning or drawing a blueprint should be part of the product development process

Step 3 *Testing*: Seven students' responses suggested making a model and running experiments or tests on it as part of the design process. One student also mentioned showing the model (prototype) to the client

Step 4 *Building*: More than half of the students ($n = 11$) believed that the engineering process focuses on building, a step in which one starts to make one's plans real

Step 5 *Improving*: One student indicated that testing the product is necessary, to make it more advanced through an iterative process

For most students, engineering design was essentially a two-step process, starting with the planning step and ending when the product is built, although some students also believed engineers were involved in testing the resulting product.

M07: Like they … draw like the work on like the blueprints and they … like draw that on paper before just go[ing] out there and build[ing] it.

From the perspective of students who commented on what would be considered to be engineering design, engineers make, build, or construct what they plan or design. Although the students sometimes suggested that different engineers would be involved in these stages, these students expressed the opinion that engineers work both behind the scenes as planners or designers and in the field as workers.

Effects of Engineering in Our Daily Life

During the interviews, the students were asked whether engineering is important, and whether they could imagine a world without engineers. With only one exception, the students pointed out that engineering plays an important role in providing the products of technology we have and use today. Their opinions of the roles that engineers play in producing these artifacts of modern society varied. Some students suggested that engineers were responsible for designing these artifacts.

F12: Uhum, yeah, if we didn't have it [engineering] we wouldn't have a lot of the technology that we have right now. [When asked what would happen if there were no engineers, she responded] Oh gosh, there'd be a lot of stuff that … we use every day that they designed, that we wouldn't have. That'd be really sad.

As might be expected from responses obtained in other categories, students questioned who would put together the artifacts of modern society, F11: Because, like if we didn't have engineers then who would put cars together and make buildings and roller coasters?

or fix those artifacts when needed.

F02: If we didn't have engineering, like if … not a lot of people knew how to fix cars and everything like somebody broke down in the middle of nowhere or something like that, like if they broke down where there was no town or gas station or anything, they wouldn't be able to go back to go where they were going or back home or anything, so that's why we need [engineers].

Other students questioned who would do the "dirty jobs" in the absence of engineers.

M01: … their purpose is like trying to help us survive, like if you've ever seen the show Dirty Jobs those are some engineers on there too, making our lives easier cause they do dirty jobs. [R2: Like?] Like garbage men, they're engineers because they go around collecting garbage for us instead of us just laying it around our yard …

While commenting on a world without engineers, one student noted that the products of the work of engineers make our lives so much easier that we have become lazy and addicted to them. She was the only participant to point out a negative side-effect of engineering artifacts.

F18: They (artifacts) help you but then again they are bad 'cause they are making other people lazy and they don't want to do things for themselves. … They help people but if you use it to much it's bad.

The Difference Between Science and Engineering

As noted previously, many students confused science and engineering. Eleven of the students seemed to be aware that science "studies nature," but eight of the participants equated science with biology and the life sciences. For these students, science involved the study of plants, bugs and the human body, and was involved in finding cures for diseases.

M10: … Scientists discover stuff and like … like cells and stuff, parts of the body and stuff. Yeah, a scientist does all that research stuff …

Thirteen students talked about differences between science and engineering, often by focusing on differences in the things scientists and engineers deal with. One student indicated that scientists work on living things, but engineers do research on cars, vehicles, and buildings. In a similar fashion, two students noted that engineers work on engines, building or vehicles, but scientists explore the world, or some aspects of the world, such as human body, plants, rocks, and so on, whereas six of the students differentiated between science and engineering by suggesting that engineers design and build, whereas scientists cure diseases or study nature.

R2: … What do scientists do?
M16: Well, they study a lot of things like I guess if you're into astronomy you'd be studying the stars and planets and things like that, ah but if you like if you're a scientist that I don't know works with chemicals and things like that you'd be working with chemicals … to come up with a cure for something like help doctors come up with a cure for something like some kind of disease or illness or rash or…
R2: Okay, what do engineers do?
M16: They build and design things, um. That's what they do

Another student expressed the difference between science and engineering by focusing on whether the subject of their work is something that is living.

M08: … to be an engineer you don't really study something living. And isn't that what a scientist is? Yeah.

Eight students mentioned similarities between engineering and science, including the goal of improving technology and life standards ($n = 2$), building things ($n = 2$), using math ($n = 1$), and doing experiments ($n = 1$). Two of these students believed that science and engineering were essentially the same.

M05. Oh yeah, it's … Like, engineering is type science and engineer is a type of scientist. Just like a physicist is a type of scientist and a chemist…

Sources of Experiences

The analysis of the interviews revealed some of the sources of the students' views of the nature of engineering. These sources included TV or the internet, their teachers and the content of the courses they studied, members of their family, books and magazines, movies about engineering, and so on. An interesting response came from one female participant who noted that the interviewers had an impact on her view of engineering. When asked where she had learned most of her information about engineering or engineers, she cited two sources, her math classes and "you guys."

Conclusions

The results of this study are consistent with prior work in the field, which suggested that elementary- and middle-school students were most likely to cite making or assembling vehicles and building structures as examples of the process of engineering (Fralick et al. 2009; Knight and Cunningham 2004; Lyons and Thompson 2006; Oware et al. 2007). The students in our sample, however, were much more likely than participants in prior work to invoke the image of engineers fixing or repairing something as part of the engineering process, and they were also beginning to understand that engineers are involved in testing products for both their functionality and safety as part of the process of fixing things.

The views of the nature of engineering that emerged in this study suggest that engineering is an active, dynamic process. Almost half of the students' drawings included some form of action, whether it was designing, planning, inventing, or creating something, which suggests that more examples of elements of design were seen in this study than in prior work.

There was no clear demarcation line in this study between students who believed that engineers design or create products and those who focused on the process by which engineers supposedly make or build the product. It was apparent in both the drawings and the interview data that engineering was seen as something that was done by a handful of skilled craftsmen.

Although elements of each step in the model of the engineering process created as part of the Boston Museum of Science *Engineering is Elementary* project could be found in the collected responses from the 20 students in this study, none of the students in this study invoked more than two or at most three steps in this model and some of these steps were mentioned far more often than others. Our results are consistent with prior work, which suggests that the views of engineers and engineering held by elementary- and middle-school students are naïve and poorly developed (Cunningham et al. 2005; Fralick et al. 2009; Knight and Cunningham 2004; Lyons and Thompson 2006; Oware et al. 2007).

An indicator that the students' views of engineers and engineering were naïve or poorly developed could be seen in the students' lack of self-confidence in their responses as shown by the tendency for the students to all respond, at some point in the interview, with "I don't know" or "I guess" and terminate the discussion of that particular topic when one of the researchers tried to clarify or confirm their responses.

When the students were asked whether engineering is a "male profession," their typical response was "no." And yet, only one of the 19 drawings depicted a female engineer, which is consistent with prior work that suggests that middle-school boys have stronger aspirations toward technologically oriented jobs than girls (Bame and Dugger 1989; de KlerkWolters 1989). The inconsistency between the almost complete absence of female engineers in the drawings and the students' beliefs that engineering is not a male-oriented profession might be the result of the belief among the girls in the sample population that "women *can* do it, but not me." This hypothesis needs to be tested in future work.

Combining the analysis of the artifacts produced by asking students to draw an "engineer or engineers at work" with the results of the analysis of individual interviews during which the students discussed or described their drawing provided insight into the students' views of the nature of engineering that could not have been obtained through the analysis of either data set by itself. First, and perhaps foremost, this combined approach to analysis showed that the students' views of engineers and engineering were unstable enough to change during the course of a single interview. One student, for example, started with the notion that engineers design theme parks only to change his mind and state that architects design it, but engineers built it. When asked a similar question in a different context, the same student changed his mind again and claimed architects built highway overpasses. A similar trend was observed with many students: When the context of the question or the object (building, machine, or high-tech electronics) changed, students' thoughts of what engineers do or who might be involved in the engineering process changed as well.

Analysis of the data collected in this study showed inconsistencies between the content of the students' drawings and their answers to the interview questions. The students' drawings could easily have been interpreted as providing evidence of a stronger understanding of the process of engineering design than was revealed in the interviews. The elements of design often appeared in the drawings, but the students did not exhibit a strong ownership of the views of engineering illustrated by the drawings, and readily departed from them at the sign of the slightest clue offered by the researchers' questions or the researchers' responses to the students' answers. The discussion of the drawings that occurred in the interviews showed that the students' views of engineers and engineering were not only fragile, or unstable, but that the students often simultaneously held conflicting views about the nature of engineering that were not apparent in the drawings, by themselves.

Although one might have expected poorly defined conceptions of engineering among 6th-grade students because of the absence of direct exposure to the field in the courses to which these students have been exposed, it was interesting to note that these students also had weak or poorly defined conceptions of the NOS. Most of the students had a hard time defining the scope of science. Because of the nature of the curriculum to which they had been exposed, many students were convinced that science only studies living organisms or find cures for diseases.

This study suggests that developers of curriculum material designed to bring an understanding of engineering into the middle-school classroom need to be aware of the preconceptions students bring to these materials that lead them to expect that engineers focus on designing or planning, making or building, and testing or checking a product, and that the process of engineering design is carried out, primarily, by males. Activities, materials, and curricula should therefore build on this foundation to provide a better understanding of the full range of work in which engineers are involved, and that engineering is not a career path limited to males.

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