MIDDLE SCHOOL STUDENTS' PERCEPTIONS OF ENGINEERING

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ABSTRACT

This paper focuses on implementing engineering education in middle school classrooms (grade levels 7-9). One of the aims of the study was to foster students' and teachers' knowledge and understanding of engineering in society. Given the increasing importance of engineering in shaping our daily lives, it is imperative that we foster in students an interest and drive to participate in engineering education, increase their awareness of engineering as a career path, and inform them of the links between engineering and the enabling subjects, mathematics, science, and technology. Data for the study are drawn from five classes across three schools. Grade 7 students' responded to initial whole class discussions on what is an engineer, what is engineering, what characteristics engineers require, engineers (family/friends) that they know, and subjects that may facilitate an engineering career. Students generally viewed engineers as creative, future-oriented, and artistic problem finders and solvers; planners and designers; "seekers" and inventors; and builders of constructions. Students also viewed engineers as adventurous, decisive, community-minded, reliable, and "smart." In addition to a range of mathematics and science topics, students identified business studies, ICT, graphics, art, and history as facilitating careers in engineering. Although students displayed a broadened awareness of engineering than the existing research suggests, there was limited knowledge of various engineering fields and a strong perception of engineering as large construction.

Keywords: *engineering education, middle school, perceptions of STEM, career awareness*

INTRODUCTION

Many nations are expressing concerns over the current state of science, technology, engineering, and mathematics (STEM) education, especially given the increased demand for, and declining supply of, skilled workers in these fields. The number of graduating engineers from U.S. institutions, for example, has declined in recent years, (National Academy of Engineering. 2005; OECD, 2006), while in Australia, the number of engineering graduates per million lags behind many other OECD countries (Taylor, 2008). A recent newspaper report (The Courier-Mail, Sept. 11-12, 2010) warned that Australia is facing "a massive shortage of engineers which, unless addressed, will hold back growth and limit innovation as the effect of the global financial crisis recedes" (p. 31). The nation has an estimated shortage of more than 20,000 engineers, a figure which continues to grow. Furthermore, female students are still underrepresented in engineering, which "has the distinction of being the most male dominated of all the professions" (Dhanaskar & Medhekar, 2004, p. 264). Indeed, "the proportion of women choosing (STEM) studies still remains below 40% in most OECD countries" (OECD, 2006, p. 2). This shortage of skilled engineers is impacting significantly on the ability of companies and organizations to undertake and complete projects (Engineers Australia, 2008).

To complicate matters, engineering does not have a high public profile in many nations. For example, in a recent report, *Engineering our Future* (www.nationalgrid.com), it was revealed that while there is a cursory acceptance of engineers and engineering among young people, parents, and teachers in the UK, there are negative perceptions underlying this acceptance. Such perceptions include a lack of knowledge and appreciation of the role of engineering in society, a view that engineering is a job rather than a profession, and a lack of interest in engineering as a career. The report highlights the need to create opportunities for young people (and their parents and teachers) to gain exposure to engineers and engineering during their educational journey—"different interventions are required at different ages" (p. 4).

One response to the above concerns is the emerging growth of engineering education during the K-12 school years, which has important implications for the future of STEM education more broadly (Katehi, Pearson, & Feder, 2009). Researchers in STEM education are exploring innovative ways to introduce school students to the world of engineering (e.g., Cunninghman & Hester, 2007; Dawes & Rasmussen, 2007; Lambert, Diefes-Dux, Beck, Duncan, Oware, & Nemeth, 2007; English & Mousoulides, 2010; Zawojewski, Diefes-Dux, & Bowman, 2008). For example, Dawes and Rasmussen (2007) developed engineering education activity kits that were implemented in secondary school classrooms to build relationships with the schools, motivate and provide role models for engineers of the future, and attract more students to a career in engineering. The activity kits were designed to be fully integrated within the school curriculum and were presented, in part, by undergraduate engineers as context-rich, group-based activities.

In this paper we address some findings from the first year of a three-year longitudinal study (funded ARC Linkage Grant) in which engineering education is being implemented in grades 7 to 9. The engineering program introduces students and their teachers to foundational engineering ideas, principles, and design processes (which draw upon the students' existing mathematics and science curricula), and aims to foster students' and teachers' knowledge and understanding of engineering in society. Specifically, we report on how the grade 7 students' responded to initial whole class discussions on what is an engineer, what is engineering, what characteristics engineers require, engineers they know from family or friends, and subjects that may facilitate an engineering career.

Engineering in K-12 Education

Engineering education in the middle school is a significant, emerging field of research. It aims to foster students' appreciation and understanding of what engineers do, how engineering shapes the world around them, how engineering utilises important ideas from mathematics and science, and how it contextualises mathematics and science principles (Dawes & Rasmussen, 2007; English & Mousoulides, 2010). Given the increasing importance of engineering and its allied fields in shaping our lives, it is imperative that engineering education be introduced to younger students. The middle school has been identified as a crucial period for either encouraging or discouraging students' participation and interest in mathematics and science (Tafoya, Nguyen, Skokan, & Moskal, 2005). Research has shown that middle school students exposed to pre-engineering experiences have more positive attitudes to science, mathematics, and engineering and have greater knowledge of engineering concepts than students taught only through traditional middle school mathematics and science curricula (Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007).

Engineering education builds on students' curiosity about the natural world, how it functions, and how we interact with the environment, as well as on students' intrinsic interest in designing, building, and dismantling objects in learning how they work (Petroski, 2003). Integrating engineering experiences within the middle school curriculum can: (a) help students appreciate how their learning in mathematics and science can apply to the solution of real-world problems, (b) lead to better preparedness of senior subjects, (c) highlight the relevance of studying mathematics and science, (d) increase awareness of engineering and the work of engineers, (e) promote early interest in pursuing an engineering career, and (e) increase students' technological literacy skills (English, Hudson, Dawes, submitted; Katehi et al., 2009). To date, there has been limited research on integrating engineering experiences in the middle school curriculum.

Furthermore, few studies have probed students' and teachers' understanding of what engineering entails, of what engineers do, and of the uses and implications of the technologies that they generate (Cunningham & Hester, 2007; Knight & Cunningham, 2004). The little research that has been conducted has indicated that people generally do not understand what engineers do, despite being surrounded by the products of engineering in their everyday world (Cunningham, Lachapelle, & Lindgren-Streicher, 2005; Davis & Gibbon, 2002; Knight & Cunningham, 2004; Lambert et al., 2007). For example, Cunningham et al. (2005) found that school teachers are more likely to believe that engineers build rather than supervise the construction of buildings. Douglas, Iversen, and Kalyandurg (2004) documented that teachers generally believe that engineering has a major impact on their daily lives and that implementing engineering concepts within the curriculum is certainly warranted. However, they believe that engineering is not an option for a large number of students and that the field is very difficult to enter at the university level.

Findings from the scant studies that have explored school students' conceptions of engineering indicate that students generally do not understand what engineers do. For instance, Cunningham et al. (2005) administered their "What is an Engineer?" instrument to over 6000 primary school students and found that they strongly conflate construction workers and auto mechanics with engineers. It is thus essential that students and teachers are assisted to understand the range and type of work that engineers do and appreciate how engineering shapes so many facets of our world and how society influences and is influenced by engineering. As Hirsch, Kimmel, Rockland, and Bloom (2005) stressed, one of numerous reasons why more students are not selecting careers in engineering is that they do not know what engineering is or what engineers do.

Furthermore, studies of first-year engineering student attrition rates have indicated that, while appropriate academic preparation is essential, students' attitudes to engineering and their perceptions of engineers on entry to university are important predictors of persistence in studying engineering (Hirsch et al., 2005; Hoffman, 2000). Given that engineering faculty members' views on engineering impact directly or indirectly on undergraduate students (Pawley, 2009), it is worth considering how engineering educators define their field.

Engineers' Perceptions of Engineering

Pawley (2009) interviewed 10 engineering faculty to see how they viewed their work of educating engineers. She identified three narratives that the research participants used in explaining their work to others as well as to themselves, namely, "that engineering is about applied science and maths, solving problems, and making things" (p. 310). The knowledge domain that the participants linked most often to engineering was science. One of the ways that they linked science to engineering was through mathematics, which they considered foundational to the science curricula. Engineering as problem solving was highlighted across almost all of Pawley's interviews, with reference to solving societal problems included frequently. Interestingly, few participants defined what they meant by "society." For some participants, a critical and defining feature of engineering was that engineers "made things," with reference to highly technical and mechanised items surrounding people as the product of engineering (p. 316).

The Carrick Institute for Learning and Teaching in Higher Education also reported that most professional engineers cited problem solving in describing their work (*Addressing the Supply and Quality of Engineering Graduates for the New century, 2008* (www.carrickinstitute.edu.au). Also strongly featured in engineers' descriptions are the first three components of the Conceive, Design, Implement, and Operate (CDIO) cycle (Crawley, Malmqvist, Ostlund, & Brodeur, 2007), a framework regarded as a significant, recent development in engineering education. Interestingly, the Institute's research revealed that engineers emphasise creativity but rarely mention the scientific foundations of the tools, codes, and models that they use.

METHODOLOGY

Participants

Five middle school classes and their teachers from three Queensland (Australia) schools (two single-sex and one co-educational) participated in the first year of the study (grade 7 in 2009; grade 8 in 2010, grade 9 in 2011). In addition, given that one of the major difficulties in inspiring school students to consider engineering as a career is their lack of knowledge and understanding of the domain (Dawes & Rasmussen, 2007; Richards, Laufer, & Humphrey, 2002; Hirsch, Carpinelli, Kimmel, Rockland, & Bloom, 2007), this study included participation by final-year undergraduate engineering students and science teacher education students from the Queensland University of Technology. The Queensland Department of Main Roads was also an important industry partner, providing access for the schools to young engineers and showcasing interesting and best practice projects related to the engineering activities developed.

Learning experiences

In the first two lessons (approx. 45 minutes duration each), students brainstormed and discussed the nature and roles of engineers and engineering, and key characteristics that engineers require. Students also identified engineers in their family and among friends. Discussions followed on the school subjects they considered would facilitate an engineering career. Snippets from a DVD, *Engineering: Design your world* (Association of Consulting Engineers Australia), were then viewed. In the next activity, the student groups explored the range of engineering fields on the eGFI website (http://www.egfi-k12.org/), namely: aerospace, agricultural, architectural, bioengineering/biomedical, chemical, civil, computers/software, electrical, environmental, industrial, manufacturing, mechanical, materials, mineral and mining, nuclear, ocean, transportation. Each student group subsequently researched an allocated engineering field and completed details on "Engineers do What?" Following this, the student groups explored some famous engineers and their inventions. A couple of engineering hands-on activities to capture student attention and demonstrate science and math principles concluded these introductory lessons.

Data collection and analysis

The component of the study reported here is qualitative in nature, with the main purpose to gain insights into grade 7 students' initial knowledge, awareness, and appreciation of engineers and engineering. Data were obtained from the verbatim transcriptions of each whole class lesson involving student/teacher interaction. Constant comparative strategies (Strauss & Cobin, 1990) were used to identify the main themes in the students' responses to each of the following questions, which were asked by the teachers during the first two lessons.

1. What is an engineer? What is engineering? What do engineers do?

2. What characteristics would an engineer have? What do you require for engineering?
3. Do you have engineers in your family or have friends who are engineers? In what field of engineering are they?
4. What are some subjects that we might want to do to prepare ourselves for a career in engineering?

RESULTS AND DISCUSSION

Results were analysed according to each of the above questions. Students' responses, however, frequently combined several different attributes within the one question and across questions. This feature reflects Pawley's (2009) finding that each interviewee's narrative, although conceptually distinct, "almost always appeared in the company of other narratives, suggesting the narratives are used in hybrid ways" (p. 317).

What is an engineer? What is engineering? What do engineers do?

Five main themes were identified in the students' responses to these questions, namely: (1) solving real-world problems, (2) dealing with large construction, (3) dealing with other fields, (4) designing, and (5) helping the community. Each theme is discussed in the following:

Solving real-world problems

Several students in each class identified engineers as people who solve real-world problems. They also articulated that problems were remedied with theoretical solutions guiding implementation for improvement. For instance, one student stated, "They find problems in the world and then think of solutions to fix those problems". The theoretical analyses engineers employ for devising solutions was also used as a way to define an engineer: "Someone who uses a scientific theory to solve everyday problems". Many engineers draw upon their theoretical understandings to propose scientifically and mathematically justifiable explanations towards problem solving (e.g., Gainsburg, 2006). Furthermore, these students purported that such solution finding has relevance to real life, though there are engineers who engage in the theoretical realm only, as this is where potential solutions can be explored (e.g., Das, 2007).

Dealing with large construction

The most prevalent perception of engineers and engineering across the classes was dealing with large and common constructions such as buildings, houses, roads, and bridges. One student in the all-girls school noted, "I have always pictured an engineer as wearing a hard hat like a building hard hat all the time". The idea that engineers engage in practical activities and not just theoretical work was evident with these students. Despite the notion that engineers actively contribute to technological developments, there were stereotypical comments from students, such as "A person that makes manmade stuff like a bridge or um a house or something". The use of the term "manmade" signifies that there may be a gender issue when considering definitions of engineers. Yet, other students were more discerning in the comments: "Someone who designs things and helps build roads, cars, or buildings" and "[people] big things; large constructions. Their definitions about engineers and what they do generally focused on rather large and obvious constructions; there were few who delved beyond the path of civil and architectural engineering.

Dealing with other fields

Reference to a wide range of engineering fields was limited and it was clear that the students were unaware of many of the 17 fields listed on the engineering website (http://www.egfi-k12.org/). One student referred to mineral and mining engineers in this way: "I always imagined that they would go underground for oil and stuff", while only one other student referred to chemical engineering ("Something, sometimes they have something to do with chemicals too). In contrast, references to "does things with cars, appliances, lights and stuff," and works with engines, machinery, and technology were made by a few students in the classes. Engineering incorporates a wide field of employment, yet students in the middle years of education have limited understanding of these fields and what it means to be an engineer in such fields.

Designing

Defining engineers as designers and planners was prevalent across the classes, with students including attributes such as disposition in their definitions of engineers and engineering. They identified engineers as creative people who use imagination to design and create, as illustrated by this comment: "A person who creates, a person who designs and a person who has a good imagination". Indeed, Einstein claimed that "Imagination is more important than knowledge" (Thinkexist, 2010) and this was also intonated by students who claimed that an engineer uses imagination and "works to extend the boundaries of planning and building objects". Some students linked the designing processes to engineers' scientific and mathematical understandings and, importantly, to an interest in using these essential engineering tools: "Someone who likes to invent things and likes using mathematics and science." Many engineers are inventors of new technologies that assist society in various ways, and although designing was considered pivotal to an engineer's identity, students recognised that engineers generally seek practical applications to their designs: "I basically think it's designing something and then trying to build it". Though comments were based largely on notions of civil engineering, the students' comments can be applicable to other engineering fields as well.

Helping the community

An awareness of engineers' role in benefitting society was directly evident in one classroom but such awareness appeared limited in the class discussions in the remaining classrooms. One student defined engineers as "Mathematicians / scientists who help conquer problems to make a solution which would benefit our society". Nevertheless, nearly all students indirectly related engineers' work as helping the community, as most identified engineers' practices as designing and building structures, including roads, buildings, bridges and so forth. Their listing of such civil structures indirectly suggested that engineers help the community.

What characteristics would an engineer have? What do you require for engineering?

The students in this study ranged in age from 11 to 13 years and were in the last year of their primary school education, yet many had already developed conceptions about engineers' characteristics. These included characteristics such as cognitive functioning, social and physical features, subject matter knowledge, and dispositions.

Cognitive functioning

Common cognitive functioning characteristics these students identified included being "smart," "imaginative," "artistic," and "creative." Indeed, creative thinking appeared pivotal to the main characteristic these students claimed were essential for engineers: "When you design something you've got to think, like let your imagination run wild". Aligned with the creative thinking was an artistic creativeness, "They have to have an artistic and creative mind in a sense". Students claimed that engineers need to "think outside the box", "thinking up concepts" and require "an abstract point of view" in order to create unique designs. A cognitive characteristic, according to one student, is the need to be decisive yet considerate of alternative designs: "Like you have to decide which idea would be the best to go with and take in all the different scenarios and stuff."

Social and physical features

Research has shown that stereotyping engineers occurs with school students and in society (Frehill, 1997; Sherriff & Binkley, 1997). Indeed, stereotyping engineers occurs in the engineering profession where engineers in the field attribute masculine and feminine attributes to particular jobs (Foor & Walden, 2009). This current study indicated that some grade 7 students stereotyped engineers as wealthy, business-like people who also do work in the field. For instance, an occasional reference was made to social features of engineers such as engineers are “rich and posh.” When sharing our classroom observations with the female teacher from the co-educational school, she was amused, outlining that she is married to an engineer and he is neither rich nor posh. Students who identified physical features of engineers included statements such as, they “wear those hats” or are “in a suit”. The former comment described the engineer as an implementer of engineering designs by wearing a hard hat on site while the latter comment appears to suggest a somewhat formal business nature that engineers may need to undertake in order to perform the job.

Subject matter knowledge

There was scant reference to subject matter knowledge as key characteristics of engineers and engineering. Comments here included references to mathematics and science: “Good at science, um they have to be pretty good at science because lots of science is involved for building objects like bridges and um just like tunnels and stuff” and “good at maths.” One student articulated that engineers need to be predictors of potential problems: “You have to think forward to huge problems that may arise”. Undoubtedly, STEM content knowledge would be required to address such potential issues.

Dispositions

As with subject matter knowledge, students rarely referred to dispositions of engineers in identifying important characteristics. Being “inquisitive” and being an “adventurer” (“because they invent things that no-one’s ever seen before”) were mentioned by students. Being “cautious”, “really careful that everything…would fit together perfectly”, “reliable,” and a “thorough checker” were also highlighted. However, one student mentioned environmental dispositions that need to be part of an engineer’s characteristics, even though the student was not sure of the details behind such a disposition: “Ah you have to be like a green thinker. I don’t know what that is. Thinking of the future and environmental effects and how you could help”. The environment is high on the international agenda (e.g., Ginsberg & Frame, 2004; Sutton, 2004). Australian state and federal governments have spent over 1.4 billion dollars in the last decade with focuses on the environment and sustainable living (The Department of the Environment and Heritage, 2004). Consequently, middle school students need an awareness that engineers play significant roles in designing and constructing a more sustainable planet where resources are not consumed faster than they are used (National Academy of Engineering, 2008).

Do you have engineers in your family or have friends who are engineers?

These students had conceptions about engineers, who they are and what they do, yet we attempted to uncover where such conceptions may have originated. It appears that personal connections or associations with engineers can influence a student’s perceptions of engineers and engineering (e.g., Davies, Spencer, & Steele, 2005; Eccles, 1994). Surprisingly, several students were able to identify engineers they knew, particularly those in their families. For instance, one student indicated that his mother is a mechanical engineer and father a chemical engineer while another student stated that his brother is studying engineering but was not able to identify the engineering field. Civil engineers were most commonly cited by these students. Nevertheless, mechanical, environmental, electrical, chemical, and software engineers were also mentioned during the discussions.

What are some subjects that we might want to do to prepare ourselves for a career in engineering?

Students across the classes recognised that mathematics and science are key subjects for a career in engineering; few mentioned technology as a preparation area. In the all-girls school, the teacher asked for some specific aspects of these subjects as well as any other content areas that could contribute to a career in engineering. Students in this class identified physics, chemistry, “algebra in maths,” trigonometry, measurement, geology, biology, information technology, and business. One student suggested history, “so you have an idea of what people have invented in the past”. Scientists and mathematicians rely heavily upon knowledge of past discoveries, how they work, and potential flaws. Insight into engineers' works throughout history is included in engineering degrees where university students gather an understanding of scientific, mathematical, and technological advancements in engineering projects (National Academy of Engineering. 2008). Learning through art was tentatively considered as a preparation for becoming an engineer by one student: “There's probably something like art maybe because you have to know what you are talking about in construction? Maybe?” Architectural engineering relies heavily on knowledge about art and artistic perspectives ((http://www.egfi-k12.org/); in addition visible engineering works need to be aesthetically pleasing and so this student's idea about art as a preparation for engineering may apply to particular engineering strands. Apart from mathematics and science, students in the remaining classes identified biology, physics, chemistry, graphics, and environmental science as other ways to prepare for an education in engineering.

CONCLUSION

This study investigated grade 7 students' knowledge of and understandings about engineers and engineering. The students' responses indicated that they had broad understandings about engineers as construction designers who solve real-world problems to assist the community. There was a strong focus on large constructions. Although the students identified design as an important feature of engineering, the notion of engineering as “design under constraint” (Katehi et al., 2009, p. 28) rarely appeared in the students' responses. This feature was built into the remaining classroom activities, where students designed and built artefacts (bridge, boat) under given constraints.

The need to address the importance of design in engineering is evident from both this study and Cunningham et al.'s (2005) survey. The latter revealed that less than a third of the respondents recognised design as one of the core features of engineering. This is perhaps not surprising, given the ages of the interviewees (grades 1-5). Nevertheless, early exposure to engineering in the world of young students is clearly warranted.

A limited knowledge of various engineering fields was displayed by the students in this study. This finding concurs with Cunningham et al.'s (2005) survey results where the top six student choices of what engineers do focused on activities in construction, building, vehicles, and machinery. The survey indicated students' identification of engineering with civil engineering, and also showed a lack of understanding about the breadth of the fields of engineering. On the other hand, the students in the present study did recognize the importance of a range of cognitive abilities including creativity, future-oriented thinking, imagination, and flexible thinking.

The study findings support national and international efforts to broaden school students' knowledge, understanding, and appreciation of engineers and engineering fields. Engineering education in schools is receiving increased support from bodies such as the Australasian Association for Engineering Education and the National Academy of Engineering (USA). Indeed, the Academy's recent “Change the conversation: Messages for improving public understanding of engineering” (2008) recommends providing a new vision of engineering in the public minds, including engineering as an inspirational, creative, and innovative field (Committee on Public Understanding of Engineering Messages, 2008). Such a vision was evident in the minds of some of our seventh-grade students.

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