Journeys into pre-college Engineering: a comparison of practices and policies in Australia and the United States

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Structured abstract

BACKGROUND
In recent years, national reports in both Australia and the United States have called for increasing the number of engineers as a means of ensuring national prosperity. Both countries have also identified that this goal begins with primary and secondary schools through both increasing the number of students with the required science and mathematics abilities to be successful in engineering and developing programs to introduce students to engineering. While technology education has long been a part of the school curricula of both countries, the formal inclusion of engineering represents a relatively recent phenomenon. The development and definition of pre-college engineering is rapidly changing in both countries, presenting numerous opportunities to learn from comparisons of the approaches taken in Australia and the United States.

PURPOSE
To explore the similarities and differences in the treatment of pre-college engineering in the USA and Australia.

DESIGN/METHOD
This research is based on reviews of national and state reports addressing pre-college engineering education in Australia and the United States. We compare how engineering content is being incorporated into national and state curriculum frameworks. Finally, we review the different types and providers of pre-college engineering activities, and explore the inclusion of pre-college engineering in the engineering education research community of each country.

RESULTS
Similarities exist across the two countries in focusing on the shortage of engineers in the labour market and the role that engineers play in maintaining national security and prosperity. There is variation in the inclusion of engineering in the educational programs of different states. However, the United States has a more developed pre-college engineering ecosystem, including a greater presence in the engineering education community.

CONCLUSIONS
Based on the results of this research, a tremendous opportunity exists for the Australian engineering education community to bring a greater research focus on P-12 engineering activities. Many states in Australia have developed 11th and 12th year engineering courses that could serve as a model for schools in the United States interested in implementing similar programs. Finally, national curriculum frameworks affecting engineering are in the process of being revised in both countries, which will have a significant effect on P-12 engineering in the schools in upcoming years.

KEYWORDS
Pre-college engineering, education policy, engineering policy

Introduction

Recent reports in both Australia and the United States emphasize the importance of Science, Technology, Engineering, and Mathematics (STEM) fields in maintaining prosperity and global competitiveness in their countries (Committee on Prospering in the Global Economy of the 21st Century, 2007; Office of the Chief Scientist, 2012). These reports also recognize that maintaining a sufficient STEM workforce begins with proper preparation and developing interest in these fields early in students' academic careers. In response to these reports, both Australia and the United States have focused on improving STEM-related curricula and increasing outreach efforts in these fields. As a result, students increasingly have the opportunity to learn about engineering prior to matriculation in a university or vocational education program.

Much of the recent dialogue in both Australia and the United States calling for more engineering graduates has focused on the shortage of engineers in the workforce. Reports in Australia have pointed to extremely low engineering unemployment rates as a sign that the labour market in engineering is undersupplied and thus programs are needed to encourage more students to pursue degrees and careers related to engineering (Engineers Australia, 2012). Reports in the United States have made very similar claims (National Science Board, 2012). However, more recent reports suggest that the need for engineers is diminishing, making this a less compelling argument for recruiting more students into engineering programs (Engineers Australia, 2013).

The explicit discussion of P-12 engineering at the national level presents a major difference between the United States and Australia. Two major policy discussions on P-12 engineering have occurred in the United States: a general discussion on the current state of P-12 engineering including an attempt at a comprehensive review of current P-12 programs (NAE Committee on K-12 Engineering Education, 2009) and a more focused discussion debating the development of a national curriculum framework for P-12 engineering education (National Academy of Engineering, 2010).

In this paper, we provide an overview and comparison of three important facets of P-12 engineering education. First, we examine the state and national curriculum frameworks to identify the extent and location of engineering content within the primary and secondary school curriculum. Second, we describe current programs and activities involving P-12 engineering in both Australia and United States. Finally, we compare the degree of inclusion of P-12 engineering in the work of the engineering education communities of both countries. We conclude with opportunities for both Australia and the United States to learn from the other's P-12 engineering practices.

Pre-college Engineering policy

Australia

Many states across Australia include engineering as part of both their K-10 curriculum frameworks and in courses leading to a senior secondary certificate of education. Engineering shows up to different degrees across the curriculum frameworks that guide the content of primary and secondary school subjects. While none of the states includes engineering as an independent framework, many do include engineering as part of their technology or science frameworks.

The frameworks of Queensland, Victoria, and Western Australia provide examples of the challenges of integrating Engineering into state curriculum frameworks. The frameworks for each of these states include sections addressing design and technology, but make no explicit mention of Engineering.

Many states are now moving towards or have already implemented the Australian Curriculum, an attempt to align the Foundation to Year 12 Curricula across all of the states.

Engineering does appear in the science curriculum, but only as one of several users of scientific knowledge("The Australian Curriculum v5.1," 2013). Further evidence of the integration of Engineering in the Australian Curriculum is limited at this time, as the technology curriculum framework will not be released until December of 2013.

Table 1 summarises Engineering course offerings in the 11th/12th year across the various states that count in the calculation of a student's Tertiary Entrance Rank (TER), a predecessor of the Australian Tertiary Admission Rank (ATAR) used as one of the criteria for university admissions (Masters, Forster, Matters, Tognolini, & Australian Council for Educational Research (ACER), 2006). New South Wales, Queensland, Victoria, and Western Australia all include explicit engineering options among their course offerings. In addition, every state includes some aspect of design and technology among their offerings with different degrees of focus on design and analysis versus fabrication.

Table 1: Engineering and related subjects that count towards TER by state

NSW	TAS	QLD	VIC	SA	WA	ACT
Engineering						
Engineering Studies		Engineering Technology	Systems & Technology		Engineering Studies	
Design & Technology						
Design & Technology	Advanced Electronics	Technology Studies	Design & Technology	Design & Technology Studies	Materials Design & Technology	Design & Technology

Overall, Australian curricula have strong integration of Engineering course offerings at the senior secondary level. Engineering content related to technological design has a strong presence in the technology curriculum frameworks of many states. However, despite engineers being significantly involved in the design of new technologies, the use of the terms "engineer" and "engineering" remain limited within the technology frameworks.

United States

Curriculum frameworks across the United States similarly show different ways and levels of integrating engineering in the P-12 curriculum. A review of the curriculum frameworks across the United States (Carr, Bennett, & Strobel, 2012) found engineering content in the frameworks of 41 out of 50 states, although the authors considered the references to engineering weak in five of these states. Of the remaining 36 states, engineering was included as part of the science frameworks in 12 states, 8 in the technology frameworks, 8 in career and vocational frameworks, 5 in combined engineering and technology frameworks, and 1 in the mathematics framework. Educational policymakers update curriculum frameworks periodically so these numbers may have changed slightly since this study was undertaken, and will probably change further as states adopt the Next Generation Science Standards, which we address later in this section.

A continuing dialogue on the inclusion of engineering in P-12 curriculum frameworks occurring at the national level presents a significant difference between the approaches taken by the United States and Australia. This dialogue includes debating the development of a national engineering framework, development of a national exam and accompanying framework related to technology and engineering, and a significant role for engineering in the most recent revision of the national science frameworks.

The report *Standards for K-12 Engineering Education?* (2010) describes the results of a committee commissioned by the National Academy of Engineering to discuss the development of a standalone P-12 engineering curriculum framework. The committee ultimately recommended against the development of a new engineering framework, citing still limited experience with engineering in primary and secondary education, a lack of qualified teachers, limited evidence on the effectiveness of national curriculum frameworks, and a P-12 curriculum already crowded with learning goals from other domains of study. Instead, the committee recommended infusing engineering content into existing curriculum frameworks in other domains, and demonstrating how engineering can be used to develop student learning to satisfy the learning goals established by existing science, technology, and mathematics curriculum frameworks.

The development of a technology and engineering exam as part of the National Assessment of Educational Progress (NAEP) represents another significant milestone in bringing engineering content to the American P-12 classroom. The exam and accompanying framework (National Assessment Governing Board, 2010) recognises both the need for technology and engineering literacy and the explicit role that engineers play in the development of new technologies.

A final recent development in P-12 engineering education in the United States concerns the development and implementation of the Next Generation Science Standards (NGSS). This is the first time that engineering has been included in a national science curriculum framework(Jackson & Sridhar, 2013), and will significantly raise the profile of engineering in the P-12 classroom. The developers of the framework also chose to use the term "engineering design" to replace the older term "technological design", acknowledging the significant roles that engineers play in the systematic design of new technologies(Quinn, Schweingruber, & Keller, 2011).

It is important to point out that despite recent efforts to standardise education across the United States with the development of the Common Core curriculum framework (Mathis, 2010), curriculum frameworks are developed and implemented at the state level. National curriculum frameworks are produced by professional societies associated with the different subject areas, and serve as guidelines which many (but not all) states use as the basis for the development of their own frameworks.

Pre-college Engineering delivery

Australia

Australia has many programs focused on generating interest in Science, Technology, Engineering, and Mathematics (STEM) fields. These include extracurricular initiatives like Formula 1 in Schools, outreach efforts from Engineers Australia, university programs, and outreach efforts designed to encourage greater participation in engineering by members of underrepresented minority groups.

Formula 1 in Schools (F1iS) is one of the most popular engineering and technology activities in Australia, engaging 40,000 students each year from ages of 10 through high school ("F1 in Schools - REA Foundation," n.d.). F1iS is sponsored by the Re-Engineering Australia Foundation, a private non-profit funder with the goal of encouraging more students to pursue careers in engineering and technology. Research on the program suggests that is has a positive effect on students' motivation to pursue a career in engineering, although the effect is more pronounced on boys than girls (Myers, 2011).

Engineering Aid Australia is a charitable organisation whose primary goal is to encourage Indigenous students to pursue careers in engineering. In partnerships with the University of Sydney and Curtin University, 46 students participated in the 2013 Indigenous Australian Summer Schools program. Grade 11 and 12 students attended a weeklong summer camp run by the Faculty of Engineering at each institution, participating in a variety of activities spanning different engineering disciplines. Student evaluations of the program show participation resulting in high levels of interest in pursuing university study in engineering and a better understanding of what an engineering career entails (Engineering Aid Australia, 2013).

Engineers Australia also plays a strong role in P-12 engineering, with numerous programs aimed at encouraging P-12 students to pursue careers in engineering. These programs included web-based resources like EngQuest that involves educational games related to engineering for lower primary, primary, and middle school students. Engineers Australia also hosts the Engineer Your Career website that provides engineering career guidance for high school students. Regional divisions host a variety of activities, including programs to bring professional engineers into school classrooms, summer camps, design competitions, classroom presentation kits, and a humanitarian engineering conference in partnership with Engineers Without Borders.

Universities play a significant role in P-12 engineering education in Australia. Almost all of the aforementioned programs rely on facilities, expertise, and labour provided by university or TAFE faculties, staff, and student. Many universities also run additional single- or multi-day workshops or engineering design challenges meant to attract students to engineering programs at their institutions.

United States

There are a huge variety of P-12 engineering programs across the United States offered by many different types of organisations. These include engineering curricula developed for use in primary and secondary school classrooms, afterschool programs designed to encourage interest in engineering, summer camps, university sponsored outreach activities, informal education via science museums, and programs that focus on increasing participation among women and underrepresented minorities. A comprehensive review of P-12 engineering programs in the United States has been done elsewhere (NAE Committee on K-12 Engineering Education, 2009) and goes beyond the scope of this paper. Instead, we provide a brief overview and example of several programs to give a sense of the scope of this work in the United States.

Two of the largest P-12 engineering initiatives in the United States are Project Lead The Way (PLTW) and For Inspiration and Recognition of Science and Technology (FIRST). PLTW is a private, non-profit organization that developed the most widely implemented engineering curricula used in the United States, used in over 4,700 schools across the country. Although research on student outcomes resulting from participation in PLTW presents mixed results, in general PLTW has been shown to have a positive effect on mathematics and science achievement and students' decisions to pursue further study in engineering (Tai, 2012).

FIRST has developed a series of robotics competitions for elementary, middle, and high school students. Over 350,000 students have participated in teams competing in the various competitions (FIRST, 2013). Participation in FIRST has been associated with the same set of positive outcomes as PLTW.

University schools of engineering sponsor numerous programs focused on P-12 engineering. These include single and multi-day workshops focused on encouraging students to be involved with engineering, programs to train teachers how to teach engineering in their classrooms, and the GK-12 program that partners graduate students with teachers to assist them with bringing engineering content to P-12 classrooms. A small number of programs also allow undergraduate students to earn both an engineering degree and a certification to teach science, mathematics, or technology. Many university programs also work specifically with women and members of underrepresented minority groups to increase their representation in engineering.

Pre-college Engineering education research

The inclusion of P-12 engineering education research differs greatly between Australia and The United States, with the United States having a much larger community dedicated to this research.

The K-12 and Pre-College Engineering Division of the American Society for Engineering Education has approximately 750 members, and is the 11th largest of the 51 divisions. At the

2012 annual conference of the American Society for Engineering Education, the K-12 and Pre-college division included 78 papers and 10 posters over 19 technical sessions (Parry, Gardner, & Zarske, 2012). The American Society for Engineering Education has also sponsored a separate workshop on P-12 engineering for the past 10 years. Although a much smaller conference, the Australasian Association for Engineering Education Annual Conference in 2012 had one session on Engineering at High School & Podcasts which included three papers related to P-12 engineering (Mann & Daniel, 2012).

Journal publications also provide evidence of a more developed P-12 engineering education research community in the United States. Since 2009, two articles related to P-12 engineering education have appeared in the Australasian Journal of Engineering Education. Over that same period, the Journal of Engineering Education published by the American Society for Engineering Education published nine articles on this subject. In addition, The Journal of Pre-College Engineering Education Research was launched in 2011.

A lack of understanding the effects of participation in P-12 engineering education programs, particularly how these experiences affect outcomes such as matriculation and retention in university engineering programs, presents a major gap in P-12 engineering education research. Despite the prevalence of these programs and the considerable financial and political support that they receive, comprehensive studies have not been done on the long-term effects of participation, making it difficult to draw conclusions about the effectiveness of these programs in increasing participation in engineering or preparing students for future study in engineering.

Conclusions

In 2001, the National Academy of Engineering of the United States recognized that numerous groups engaged in a wide variety of P-12 engineering outreach activities, but relatively little was known about the scope or effect of these programs. To address this gap in understanding, they formed a Committee on the Public Awareness of Engineering that conducted a survey of the various groups doing engineering outreach. The resulting report, *Raising Public Awareness of Engineering* (2002), described finding a variety of high quality engineering outreach programs, and encouraged the organizations responsible for these programs to continue their efforts. However, they also found little evidence of the long-term effectiveness of these programs, and recommended the development of metrics and evaluation criteria and more rigorous assessment of outreach programs. This led to a more systematic approach to P-12 engineering outreach, and prompted numerous other national discussions on the role of engineering in the P-12 educational system.

The current Australian P-12 landscape in many ways resembles what was happening in the United States when *Raising Public Awareness of Engineering* was released. Numerous universities, engineering professional organizations, private foundations, and primary and secondary schools provide a variety of opportunities for young people to explore engineering. However, relatively little research currently exists on the effects of these programs, and P-12 engineering does not appear to be fully embraced by the Australian engineering education research community. This is a major gap in the research literature and could provide many interesting research opportunities to those interested in performing studies in this area.

Significant opportunities also exist for P-12 engineering providers in The United States to learn from the experiences of their counterparts in Australia. In particular, the prevalence of engineering and technological design opportunities in the senior secondary curricula of many Australian states provides an interesting example of how engineering content can be delivered at this level. The upcoming release of the technology frameworks portion of the Australian Curriculum, this will continue to be a dynamic component of the Australian engineering education environment worthy of future research.

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