Perceptions of Engineering Among Senior Secondary School Students

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By

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This thesis was prepared for the School of Civil Engineering at the University of Sydney, Australia, and describes the perceptions of engineering among senior secondary school students. The opinions, conclusions and recommendations presented herein are those of the author and do not necessarily reflect those of the University of Sydney or any of the sponsoring parties to this project.

Abstract

Existing research and statistics show that the engineering workforce in Australia and globally is losing technical and creative minds to other professions partly due to secondary school students choosing not to study engineering at a tertiary level, which may be due to a misperception or a lack of perception of what engineering is and what engineers do. The objective of this research is to obtain an understanding of Australian senior secondary school students (Years 11 and 12) regarding their view of engineering and themselves within an engineering context and compare these findings with similar research on university engineering students.

The data for this study was obtained using an anonymous online survey directed at Year 11 and 12 students in New South Wales who are currently enrolled in STEM subjects as part of their Higher School Certificate. The survey was designed to elicit personal narratives regarding students' perceptions of engineering and their imagined roles within the field.

The findings revealed that many secondary school students have a lack of perception of engineering, being unsure of the characteristics and roles of an engineer, and of how their current study of mathematics and science relates to engineering. Students who had a close friend or relative that is a professional engineer were more likely to have existing perceptions of engineering, with many of them focusing on the technical components of the profession.

Without the assistance of educators, students will continue to depend on their limited or inaccurate knowledge of the engineering profession and make education and career choices based on that knowledge. Educators can develop students' knowledge by establishing the relevance of secondary school subjects in real world professions such as engineering and providing more opportunities for practical application and experience.

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1. Introduction

1.1 Introduction to Research

The field of engineering is a complex and multi-faceted profession that many groups and individuals, especially students and educational institutions, fail to accurately understand, perceive, or identify with. As a result of this, among other reasons, the engineering workforce in Australia and globally is losing technical and creative minds to other professions. This loss comes in the form of engineering graduates leaving the profession, engineering students not graduating from university, and school students choosing not to study STEM subjects at school or engineering at a tertiary level.

Existing research connects this ‘leaky pipeline’ (Palmer, Tolson, Young and Campbell, 2015) in engineering with the palpable lack of engineering identity that exists among students, in conjunction with the misperception or even lack of perception of what engineering is and what engineers do. It has been proposed by Seymour and Hewitt (1997) that students who leave engineering do not understand it as a field in the same way as professional engineers or educators, and that this misunderstanding is even more pronounced in a secondary school environment. Self-efficacy, or one’s belief in their ability to accomplish something, has also been found to be a crucial factor in career selection by adolescents (Bandura et al., 2001), however, one’s self-efficacy is based on their conceptual understanding of that career or profession, which may be inaccurate.

Much research exists on this topic aimed at university students in an attempt to understand their perceptions and engineering identity to implement new programs and pedagogical approaches to address misperceptions and inaccuracies, as well as help students develop a deeper connection with engineering, with the hope that they will persist throughout university and a career in engineering. However, as stated by Lyons and Thompson (2006), the first step to increase participation and reduce attrition in engineering and other STEM subjects is to inform K-12 students about engineering disciplines and reduce inaccurate perceptions of these fields. To accomplish such a task, a deep yet broad understanding of the existing perceptions among K-12 students needs to be obtained (Knight and Cunningham, 2004).

The objective of this research is to obtain an understanding of Australian senior secondary school students (Years 11 and 12) regarding their view of engineering and themselves within an engineering context. Thus, the research will seek to answer the following questions:
(1) What are the perceptions of engineering practice among senior secondary school students?
(2) What factors do senior secondary school students perceive as differences between themselves and engineers?

The findings of this research compliment a similar study that has been conducted as part of an undergraduate thesis by Seo Woo Bae at the University of Sydney, who focused on the perceptions and engineering identity among university students using the same theoretical approach and methodology. Combining the results of both studies and analysing them concurrently has resulted in a deeper understanding of how perceptions develop over time from Year 11 through to final-year undergraduate engineering coursework, and has highlighted areas of inconsistent development and factors influencing engineering identity formation.

A variety of factors have been found to influence the perceptions of engineering among students at all levels, with some factors being more influential at particular stages in a student's development. The effect of a close connection or association with a professional engineer is explored, as well as the gender of the student and the subjects they study at school. This leads to a discussion of what educators can do to assist students who have a misperception or an absence of perception, and how they can generate an interest in engineering among students.

This report commences with a review of existing literature on the broader topic, including identity and perception theory, the existence and impact of engineering perceptions on society, the factors that influence these perceptions, and methods in which perceptions have been identified or measured previously. This is followed by a description of the theoretical frameworks that are applied to this research, including conceptual ecology, threshold concepts, possible selves, and stage theory. The methodology for this research is then described and followed by a report of the findings. These findings are discussed within the context of the theoretical frameworks, implications are identified, and possible improvements to the methodology are proposed. The report concludes with a summary of the items discussed and future work is proposed to further this research.

This research has significance within Australian metropolitan secondary schools, particularly in New South Wales, by giving them a generalised sample of students' perception of engineering, leading to potential changes in pedagogical approaches. It will also hold significance for Government education departments who have the means and power of implementing programs and adjusting curriculum to account for the findings. Furthermore, the research will be significant for universities and the professional engineering industry by extending the existing research on engineering perceptions of university students, allowing them to develop new approaches to addressing the 'leaky pipeline' from an earlier point in a student's education. It lies within the interest of these bodies, and Australia as a nation, to nurture the study of engineering from an early age and place greater emphasis on increasing the number and quality of engineers to ensure development and growth of the industry in the future.

1.2 Pre-research Reflexivity Statement

The purpose of the pre- and post-analysis reflexivity statement is to communicate to the reader the positioning and shift in understanding of the researcher. This is intended to inform the reader on how the researcher's own perceptions, knowledge, and context may influence the findings of the research. As such, it is written in first-person by the researcher as follows.

I am an undergraduate civil engineering student who is conducting this research as part of my final year thesis project. I attended an independent secondary school in the Sydney metropolitan area and studied Extension Mathematics, Physics and Chemistry as part of my Higher School Certificate in 2013. My undergraduate engineering degree has spanned over a period of 7 years as a result of overseas travel, and I have worked part-time for approximately three years as an undergraduate engineer in the private and public sector. I had limited exposure to engineering prior to commencing my undergraduate degree and chose to study engineering due to multiple relatives who recommended it as a worthy and reliable career. Those relatives, of which there were three, were all qualified mechanical engineers working in the mining industry in various countries.

As a result of my extended period at university as an undergraduate and experience working in an engineering role, I have been careful to identify any bias on particular research or findings due to personal experiences. Such bias includes the development of a perception of engineering based on work experience that may not reflect the entire range of activities possible as an engineer. I also admit that I have felt that my undergraduate studies have not prepared me for particular aspects of the engineering profession, for example an over emphasis on technical work and a lack of awareness of all the possible roles and responsibilities of engineers.

I have an interest in education and working with youth which includes opinions on the ways in which education and career advising should be approached in a school and university setting. It is possible that these opinions and interests may create bias in surveying literature and analysing results, potentially leading me to favour certain research or outcomes. As such, I have sought to remain mindful of my own opinions and approach this research as neutrally and fairly as possible.

1.3 Contributions

Together with Seo Woo Bae, we developed the idea for the research topic before dividing the work accordingly. Together we selected and adjusted the survey instrument, developed the project proposal, and applied for ethics approval. I was responsible for all research relating to secondary schools, including communicating with schools, sending out information, receiving survey responses, and analysing the data. Seo Woo was responsible for all research relating to university students. Once the data was analysed, we shared results and wrote individual theses focusing on our topic with reference to each other's findings.

2. Literature Review

2.1 Introduction

The information in the following literature review was compiled from a range of credible sources, including scholarly articles, annual reviews, peer review conferences, and published books. These publications were generally extracted from journals such as the Australasian, European, and International Journal of Engineering Education, IEEE Education Society Conferences, and more. Publications were focused on the topics of identity theory, engineering identity, engineering perceptions, Australian education reports, and Australian engineering industry reports. All information was sourced through the University of Sydney Library or ResearchGate.

2.2 History and Analysis of Identity and Perception Theory

Identity, as a broad topic, can be defined as "being recognised as a 'certain type' of person." (Gee, 2000). An individual is not limited to only one identity, but rather, multiple aspects of identity interact to create the entire persona that makes them an individual.

In the context of engineering, identity can be most simply expressed as the extent to which an individual identifies themselves as an engineer and with the profession of engineering (Morelock, 2017). Applying Gee's four factors of identity in an engineering context, Capobianco, French and Diefes-Dux (2012) defined engineering identity as the interaction of academic identity (self-image of the individual as a student), school identity (individual's affiliation with their school or university), occupational identity (individual's understanding of the engineering profession), and engineering aspirations (individual's aims or objectives of becoming and engineer).

A careful analysis of these four factors reveal that engineering identity and engineering perception are unavoidably connected. An individual's engineering identity is based on their perception of the profession and study of engineering. As perception is based on life experience and learning, researchers are finding that people tend to choose behaviours whose meanings are congruent with their own self-meanings. Thus, it is likely that career interests of students reflect similarities in their self-concepts and their perceptions of the career (Pierrakos et al., 2009). By understanding identity theories and perceptions of engineering, researchers can gain a deeper understanding into why students choose to study engineering, and why they may or may not persist with it (Patrick, Borrego & Prybutok, 2018).

2.3 Impact of Engineering Perceptions and Identity on Society

2.3.1 Impact on Individuals

Most school students have little or no meaningful exposure to engineering practice throughout high school, yet due to an interest in mathematics and science, they choose to study engineering at university (Godwin, Potvin, Hazari and Lock, 2016). As the ability of many students to define an image of a professional in their field does not develop until late in their academic career, some students may become depressed or dissatisfied when they feel it is too late or not feasible to switch fields (Pritchard and Mina, 2013). As such, it is important to ensure that their perception of engineering is accurate to avoid a disconnect(ion) between the profession and the individual's identity. As engineering is an interdisciplinary field, consideration must be taken as to the extent to which those participating in the practice associate with the profession and identify themselves as engineers. Without alignment between the individual's identity and the identity of an engineer, the individual may feel as though they do not belong (Patrick, Borrego and Seepersad, 2018). Understanding the role of an engineer can be transformative for an individual if the role aligns with their identity, but troublesome if there is a misalignment that is perceived as unresolvable. This happens particularly when the technical aspect of engineering is emphasised over the social aspect, causing engineers to experience conflict between their identity as a technical person and the reality of their role (Bennett and Male, 2016).

2.3.2 Impact on Educational Institutions

High attrition rates at university and amongst graduate engineers has led to concerns that students may enter tertiary engineering education without understanding the reality of studying engineering and the work involved in the profession. If students have an inaccurate perception of engineering that does not align with their identity, they are less likely to choose to study it at a tertiary level. Many students who leave engineering and other STEM courses do not understand the nature of the profession properly and could have been very contented engineers had they persisted through university (Montfort, Brown and Whritenour, 2013).

If students feel as though they lack engineering identity while they are enrolled in an undergraduate engineering course, they are unlikely to persist in their degree and graduate (Patrick, Borrego & Prybutok, 2018). This was supported by Tonso (2006) when she suggested a cause of high attrition rates is due to a lack of congruency between engineering as a field of study and profession, and the identity of an individual. Students who align their career choice with their attainment values (sense of self) are most likely to persist throughout university. In fact, attainment values have been shown to be even more important in persisting in university than the student's interest in the course or subject (Matusovich, Streveler and Miller, 2010).

In the United States, approximately half of engineering students do not complete their degree, with half of these discontinuations occurring in the first year of university (Dabbagh and Menascé, 2006). Due to similar trends in Australia, the 2008 review of Australian education (King, 2008) made a similar recommendation, but with an emphasis on raising the public perception of engineering, especially in schools, by increasing the visibility of the innovative and creative nature of engineering and the range of occupations available within engineering.

2.3.3 Impact on the Economy and Labour Force

More than half of engineering graduates in Australia do not go on to work in engineering-related roles (Palmer, Tolson, Young and Campbell, 2015), with only 29% of engineering graduates seeing themselves remaining in engineering for more than 10 years. Concerning attrition rates from engineering courses, 35% of students that commence undergraduate engineering studies did not complete them as measured in 2010 (Trevelyan and Tilli, 2010), with this figure increasing to 39% in 2018 (King, 2019). These high attrition rates are a loss to the qualified workforce as well as a loss in public investment (Godfrey, Aubrey and King, 2010), and are commonly referred to as the "leaky pipeline." (Palmer, Tolson, Young and Campbell, 2015). However, in reality the situation may be more complicated. As engineers are promoted to managerial roles, they may lose the title of an engineer and are therefore not considered as engineers from a statistical point of view, yet still work in an engineering job. Also, viewing the "leaky pipeline" as a loss may be narrow minded as it may in fact be beneficial to other areas of the economy. As engineers use their skills in other professions, the economy as a whole can benefit from their skills and attributes.

The National Academy of Engineering (NAE) in the United States of America (2008) argues that although the majority of individuals will never become engineers, we can all benefit from a better understanding of what engineers do and the role they play in the creation of technology. In particular, there would be a positive impact on policy makers if they were to understand the need for increasing technological skills and capacity in a nation.

The 2014 Engineering Workforce Review stated that "Engineering-related work powers many of the key industries on which Australia's current and future prosperity relies. The quality and supply of engineering skills are vital to boost the global competitiveness of Australian industries such as Mining, Construction, Manufacturing and a range of sub-sectors of the Professional, Scientific and Technical Services industries." Similarly, the State of Engineering report (2018) determined that engineering contributed $93 billion to the Victorian state economy from 2016-2017 via engineering enabled industries, representing 25% of gross state product.

As engineering is clearly a vital component of the economy and sustaining a high standard of living in Australia, it is of great importance and interest to ensure that the general public, and particularly school and university students, have an accurate and educated perception of engineering to ensure students are graduating and finding success and fulfilment in a career in engineering.

2.4 Existing Perceptions of Engineering

2.4.1 Perceptions among the General Public

The National Academy of Engineering (2008) found that most Americans viewed engineers in a positive light, however they have a very poor understanding of what engineers do on a day-to-day basis, failing to understand the vital characteristics of an engineer such as creativity, teamwork, and communication. This is the same in Australia, with most of the community having a stereotypical perception of engineers and not understanding the breadth of their role in sustainability, medical technology, financial systems, and entertainment and media (Burnett et al., 2019).

2.4.2 Perceptions among University Students

The Royal Academy of Engineering has pointed out that young people and their influencers hold outdated views of engineering and, as a result of these misperceptions, are not pursuing careers in engineering (Morgan, 2014). For example, Bennett and Male (2016) found that when Australian second- and third-year students were asked to imagine their personal role as an engineer, most students linked to technical requirements and specialisations. This finding was consistent with Pritchard and Mina (2013), who found that the technical problem-solving role of engineering was the most common response to the role of engineers among a group of American first-year students.

In contrast to these findings, Bennett, Kapoor, Kaur and Maynard (2015) compared students' perceptions of engineering to the Engineers Australia Competency Guidelines, finding that 86% of first year engineering students in Australia perceive 'Professional and Personal Characteristics' as the most important characteristic for an engineer. Of far less perceived importance were the characteristics of 'Knowledge and Skill' (4%) and 'Engineering Application Ability' (11%), which may reflect a lack of awareness about the technical knowledge and skills demanded by engineering work. Similarly, it was found that American students who participated in an engineering entrepreneurial simulation at university had a shift in their perception, coming to believe that professional skills are more relevant to engineering than technical skills (Dabbagh and Menascé, 2006).

Another study found that American students emphasised the technical components of engineering as well as professional characteristics, but failed to recognise the importance of understanding contemporary issues and current affairs, and obtaining a broad, multidisciplinary education (Towers, Simonovich and Zastavker, 2011).

Jocuns, Stevens, Garrison and Amos (2008) made an interesting observation in their research that some students perceive engineering in a scientific/research context, relating it to theories, processes and mathematics, while others perceive engineering as an occupation, relating to conditions of work and communication skills. Typically, students' perceptions changed from science-based early in their degree to occupation-based further into their education. This was reflected by the shift in emphasis that students placed on the mathematics and scientific skills being a key characteristic of a good engineer early in their degree, to a greater emphasis on communication skills and working in teams in their final year.

Bennett and Male (2016) found that among the greatest perceived differences between first year engineering students' perception of themselves, and their perception of an engineer, was the required level of creativity. This same perception was found by Pritchard and Mina (2013) and Jocuns et al. (2008). Students' perceptions of day-to-day activities as an engineer also shifted from hopeful expectations to more mundane and less high status. Pritchard and Mina (2013) found that first-year engineering students tend to perceive the role of an engineer as "making the world a better place", while final year students tend to have had this optimism diluted.

The reason for the differing perceptions found in these studies may be due to the variation in culture among universities and the emphasis they place on different aspects of engineering. Some universities may structure the coursework around the technical component of engineering, while others may emphasise practical components. These variations are likely to influence the responses of the students.

2.4.3 Perceptions among Secondary School Students

Students in the early years of high school in the United Kingdom, typically aged 12-14 years old, believed that engineering and science are "too hard" and that there is no point in learning them as they lack real world application. Students also identified with the stereotypical image of engineers as wearing "oily overalls and holding spanners" (Bevins, Brodie and Brodie, 2005). Similarly, a study looking at the perceptions of engineering from a female secondary college in regional Victoria, Australia, found that female 10th grade students were unlikely to choose engineering as a career choice due to a lack of interest in the perceived image, a lack of knowledge, and limited recognisable role models. Female students commonly perceived engineering as a profession for males who work with metal, technology, and electronics. Like university students, they also had limited knowledge regarding what engineers do and the environments in which they work (Darby, Hall, Dowling and Kentish, 2003). However, much effort has been put into attracting students into engineering through outreach programs and marketing schemes, so these findings may no longer be applicable and present an opportunity for future research.

In a 2013 American study of the conceptual understanding of engineering by middle school students by Montfort, Brown and Whritenour, it was found that approximately half of the students associated engineering with "designing" or "planning" things that were to be built. Many students who did not reference design or planning focused more on “building” or “fixing” things. The focus on the design and implementation roles of engineers reveals a possible gap in knowledge of the conception and operational duties of a professional engineer. This may show that students’ perceptions of what engineers do is limited to certain responsibilities and this may deter them from studying engineering due to a lack of knowledge of all potential opportunities within the profession.

A worldwide study by Kőycű and de Vries (2015) found that upper secondary school students generally have a broad understanding of engineering and tend to have a positive attitude towards it. When asked to draw a mind map reflecting what engineering is, common words that appeared related to the research dimension of engineering (e.g. calculating, researching, analysing), the development dimension, the managerial dimension (e.g. teamwork), and the economic/social dimension (e.g. money, government). Despite this outcome, the range of perceptions of engineering in Australian universities may mean that this outcome is not reflective of the current situation in Australian secondary schools.

2.4.4 Perceptions among Junior School Students

By analysing the way that grade 3-12 students drew an engineer and described what the engineer was doing in their drawing, Knight and Cunningham (2004) were able to deduce that junior school students most commonly perceive engineering as “building things”, with older students being more likely to recognise the role an engineer has in the design process. Along with building things, a common perception among all students is that engineers fix things, such as engines and computers. These findings were supported in a similar and more recent study aimed at sixth-graders by Karatas, Micklos and Bodner (2010), and aimed at first to fifth-graders by Capobianco, Diefes-Dux, Mena and Weller (2011).

A similar study that involved drawing and explaining was conducted on K-12 students to understand their perceived differences between engineers and scientists (Fralick, Kearn, Thompson and Lyons, 2008). A similar result was returned, showing that students tend to perceive engineers more as a ‘doer’ or ‘worker’ rather than a ‘thinker’, as most drawings showed engineers with building tools or around vehicles. Most explanations of drawings reflected lower level mental functions and physical actions such as operating machines or making things rather than higher level mental functions such as explaining or experimenting, which were more commonly associated with scientists. Most interestingly, 29% of students did not draw an engineer at all, while only 2% did not draw a scientist, indicating that while an inaccurate perception of engineering may exist, there may also be a complete lack of perception as to the role of an engineer among young students.

2.5 Factors Influencing Students' Engineering Identity and Perceptions

2.5.1 The Media

Students aged 12-14 in the United Kingdom reported that there is a lack of identity in engineering, mainly because it does not receive as much attention in the media as sport and current affairs. They argue that engineering should be portrayed in a more contemporary and exciting way to generate a more appealing identity that will draw students towards it (Bevins, Brodie and Brodie, 2005).

2.5.2 Role Models, Mentors, and Outreach Programs

Dehing, Jochems and Baartman (2013) found when interviewing recent engineering graduates that mentors, most commonly senior engineers, were a strong influence on the development of engineering identity and an accurate perception of engineering. Lyons and Thompson (2006) observed how primary school students drew engineers after taking part in an outreach program that paired engineering graduates with school science teachers to co-develop and co-teach lessons on engineering. These drawings were compared with students who were not part of the program to assess the effectiveness of the outreach program. As a result of the outreach program, students had clearer perceptions of engineering, with their images showing more accurate artefacts such as computers, formulas, and models. They also showed a broader range of engineering disciplines and wrote about high order functions involved in engineering such as testing, experimenting, designing, and researching.

2.5.3 Teachers and Educational Institutions

Schools offer little opportunity for students to connect science and mathematics with professionally useful knowledge, resulting in many students never considering engineering after high school, or dropping out of engineering courses due to being inadequately prepared for them (Douglas, Iverson and Kalyandurg, 2004). Secondary school students considering engineering at university should be informed about all of the career possibilities for engineering graduates, and that they are just as likely to work outside of engineering as they are to work in it (Palmer, Tolson, Young and Campbell, 2015). If educators do not help students to understand their potential roles as engineers or in other professions, students will depend on limited and often inaccurate knowledge of the profession and make uninformed decisions based on that knowledge (Male and Bennett, 2015). Often one of the major issues is that teachers are no better informed on careers such as engineering than the students, calling for a need for external partners to come into schools to assist in guiding students who aspire to a career in engineering (Dawes and Rasmussen, 2007).

Within universities, engineering educators can encourage misconceptions about engineering practice by placing excessive emphasis on technical activities. This results in students who more heavily identify with engineering in a research institute environment, rather than a commercial environment similar to what they are likely to work in upon graduation (Trevelyan, 2011).

2.5.4 Professional and Industrial Experience

Du (2006) found that a student's professional engineering identity is strengthened when working in a practical engineering environment or on project-based learning activities. This was supported by Dehing et al. (2013) who found that industry experience throughout university had a major influence on a student's identity as an engineer. Not only was the professional work experience useful in developing engineering identity by being part of real-life work and project-based learning, it was also useful in creating a social network which carried with it a wealth of engineering knowledge.

2.5.5 Family and Friends

There is a strong familial influence on engineering career choice, particularly from siblings or extended family members, because it allows an individual to see a person whom they identify with thrive in the profession (Godwin, Potvin and Hazari, 2014). While engineers may pass on their engineering-related knowledge, interests and aspirations to their children, one study found that 88% of engineering parents don't explicitly teach engineering to their children, but rather, knowledge and aspirations are transferred through general discussions and teaching fundamental principles such as problem-solving, rational thinking and creativity (Dorie and Cardella, 2013).

2.5.6 Maths and Physics Identities

Godwin, Potvin, Hazari and Lock (2016) conducted a study that looked at commencing university students' mathematics and physics identities by researching their performance/competence beliefs, interests in the subject, and if they are recognised by others as someone who associates with the subject. They found that physics identity was the strongest predictor of engineering career choice, especially for men. In comparing students who completed their first year of engineering identity with those that did not, Pierrakos et al. (2009) found that both sets of students believed that a strong ability and interest in mathematics and science is fundamental to engineering, showing that an ability to perform in mathematics and science is a common element of students' perceptions of engineering and can result in them choosing to study it at a tertiary level.

2.6 Measuring Engineering Perceptions and Identity

There have been a range of different tools and techniques used to explore the engineering identity and perceptions of the general public, university students, and school students. The most common of these tools are surveys and interviews, however some researchers have created quantitative tools for measuring engineering identity and perceptions such as the Engineering Identity Development Scale (EIDS) by Capobianco, French and Diefes-Dux (2012), or the Engineering Student Identity Scale (E-SIS) by Pierrakos, Curtis and Anderson (2016). These scales have been structurally validated and used to determine the salience of engineering identity at different stages throughout university.

Some studies have also employed common identity theory to explore how it applies in engineering education. An example of this is the PCIR theory, used by Patrick, Borrego and Seepersad (2018), in which they developed a survey that measured the performance/competence beliefs, interest, and recognition of undergraduate students at all levels relating to their mathematics, physics, and engineering identity.

2.6.1 Measuring Engineering Perceptions and Identity among University Students

Bennett and Male (2016) explored the concept of 'possible selves', which are students' projections about what they hope and expect to become, and compared this to their understanding of the role of engineers, which they identified as a threshold concept in engineering education. Their study used the concept of presage thinking of undergraduate students, such as their prior experience and knowledge of engineering, in an attempt to identify what students want to achieve as engineers and what their perceptions of engineers are. The research included a survey as part of a two-hour workshop conducted at a large urban Australian university with 49 undergraduate engineering students. The students were asked to write down what they wanted to achieve as an engineer and to answer questions regarding the characteristics of themselves, of engineers, and the role and daily activities of engineers.

Bennett, Kapoor, Kaur and Maynard (2015) took a similar approach by using the concept of 'possible selves' to survey 1100 Australian first-year engineering students to determine their perceived characteristics of an engineer, the difference between these characteristics and how the student perceived themselves, and how their university studies may contribute to their development as an engineer. The authors compared the perceived characteristics with the Engineers Australia Competency Guidelines to assess the accuracy or relevance of the students' perceptions. This approach has also been used in American studies of undergraduate engineering students, comparing their perceptions to the Accreditation Board of Engineering and Technology (ABET) Engineering Criteria 2000.

While many studies have focused on first year engineering students, Meyers et al. (2012) used stage theory by conducting a 30-question survey to students in different year levels of their degree, recognising that engineering identity and perceptions would change throughout the duration of their course. The survey was adapted from a study conducted by Jeffrey Arnett (2000) which sought to identify the age at which college students identify as adults. A similar concept was applied by Meyers et al. (2012) to determine the stage at which students identify as engineers as well as the factors they consider most important in identifying as an engineer. Furthermore, in a longitudinal approach by Jocuns et al. (2008), interviews were conducted with 4 engineering students at 4 different universities over the 4 years of their degree to see how their perception of engineering changed over the course of their degree. The interview included questions that sought to identify what students considered a "good engineer", what their daily tasks would be, and how they would compare themselves to other engineering students.

Godwin, Potvin, Hazari and Lock (2016) used the PCIR theory to look at how multiple subject-related identities of 6772 commencing university engineering students, such as mathematics and physics identities, along with students' agency beliefs, could predict students' engineering career choice. Understanding the beliefs that precede engineering identity development will help educators understand why students choose to study engineering as well as the reasons why they move away from it, such as a conflict in their perception of engineering and their view of themselves and their career aspirations.

Pritchard and Mina (2013) had a unique approach in their interviews with students by interviewing non-engineering students as well as engineering students. They asked both sets of students to describe what engineering is and what it means to be an engineer and compared the responses to see what perceptions exist among engineering and non-engineering students.

2.6.2 Measuring Engineering Perceptions and Identity among Secondary School Students

A multinational study by Kőycű and de Vries (2015) required upper secondary school students to create concept maps to portray their perceptions of engineering. These maps were supplemented with a questionnaire containing 65 items, in which approximately half related to attitudes towards engineering and half towards students' concept of engineering.

Montfort, Brown and Whritenour (2013) focused their study on conceptual understanding of secondary school students, which refers to how a student perceives engineering in relation to the world around them. Instead of teaching engineering as an entirely new concept, conceptual understanding is about building on what a student already knows about engineering and how it fits into their world. The purpose of this study was to understand firstly what perceptions exist among students, and how those perceptions relate to their ability to learn about engineering. The researchers argue that if engineering education continues without understanding the students' conceptual understanding, it is likely to be met with a similar disappointing level of success.

2.6.3 Measuring Engineering Perceptions and Identity among Junior School Students

The "Draw a Scientist Test" (DAST) has been widely used for over 50 years to determine how students, particularly in primary and middle school, perceive engineers. This has been amended in several studies to the "Draw an Engineer Test" (DAET) (Knight and Cunningham, 2004; Fralick, Kearn, Thompson and Lyons, 2008; Darby, Hall, Dowling and Kentish, 2003; Karatas, Micklos and Bodner, 2010; Capobianco, Diefes-dux, Mena and Weller, 2011). This is commonly followed with a short survey or interview, in which the participant describes what the engineer in their drawing is doing. The image and responses can then be coded to provide a sample of common perceptions of the role of engineers. Variations have been made in which students undergo engineering programs for a period leading up to the DAET to measure the effectiveness of engineering programs in junior school and high school (Lyons and Thompson, 2006).

A way to introduce engineering to primary school students has been explored by Pantoya, Hunt and Aguirre-Munoz (2015). This involves linking engineering with literacy instruction by reading engineering-themed children's books with young students. This method provides an introduction to engineering vocabulary and communication patterns, helping students understand the role of an engineer in a basic way, and develop an engineering identity by helping students imagine themselves as an engineer.

2.7 Conclusion of Literature Review

There has been much research into understanding the perception which individuals have of engineering and the identity students have with the field and profession of engineering. Much of this research has yielded a variety of results, concluding that there is, in general, a lack of understanding among students, and sometimes no understanding, regarding what engineering is and what it involves. This has been shown to be the case for primary school students, secondary school students, university students, and the general public. This has negative effects on individuals, educational institutions such as universities, and the economy and labour force.

There has been a clear emphasis on researching these concepts among university students. However, by this stage in a student's academic career, they may feel it is too late to switch fields. This could potentially be avoided by placing a greater emphasis on ensuring secondary school students develop an engineering identity and an accurate perception of engineering, before considering tertiary education and their future career. This will allow them to make more informed decisions that align with their values and goals.

Based on the findings in this literature review, research will be conducted on the perceptions of engineering held by senior secondary school students (Years 11 and 12). The existing survey model introduced by Bennett and Male (2016) will be applied to senior secondary school students in New South Wales, Australia. By applying an existing survey, the outcome of the study will show what perceptions of engineering exist within secondary schools, creating a basis for which action can be taken to address any misperceptions that may exist. This research will build on other studies on secondary school students, of which few exist, and assist in validating Bennett and Male's study (2017) by applying it in a different context.

3. Theoretical Frameworks

3.1 Conceptual Ecology

Conceptual ecology is the theory that students have "common sense beliefs" which influence their learning (Halloun and Hestenes, 1985). In other words, students do not begin the study of a particular topic without any prior understanding of or experience with the topic. All new information they learn is mentally filtered based on prior experiences and knowledge of that topic. This theory applies not only to academic topics such as school subject areas or fields of study, but also to careers and professions (Montfort et al., 2013). According to the constructivist theory of learning, context and the content of an individual's existing knowledge has a significant impact on learning and understanding (Bransford et al., 2000), and therefore two individuals may conceptualise or understand a topic very differently. Of interest in this study is the concept of engineering and how, due to the unique experiences and varying contexts of individuals, it is perceived in different ways by individuals.

3.2 Threshold Concepts

There exist concepts that, when learned and understood, reveal new ways of thinking. These transformative ideas, known as threshold concepts, can often be troublesome and difficult to grasp by students (Meyer and Land, 2003). This may be because they are conceptually difficult or use unfamiliar language (Male and Bennett, 2015). It is proposed that one such threshold concept for students is 'the role of engineers' (Parkinson, 2011), which, when understood, can provide greater meaning and motivation to the study of engineering. Being such a diverse field of study and profession, this is not to suggest that there is one particular role of engineers that is correct and must be understood by engineers, but rather, a wide range of roles which, when all considered and understood, can become transformative for the student. This study utilises this framework by asking students to describe what the roles of professional engineers might look like and what characteristics they might have.

3.3 Possible Selves

The concept of possible selves refers to an individual's projection about what they hope to become, what they expect to become, and what they fear becoming (Markus and Nurius, 1986). This is comprised of cognitive manifestations of the future while maintaining the present self-concept which creates a link between cognition and motivation, thus inspiring action to move towards or away from the conceptualised possible self (Schnare, MacIntyre, and Doucette, 2012). Put most simply, the framework of possible selves identifies how an individual moves towards realising their future persona to achieve or avoid future events (Bennett and Male, 2016). The present study is based on this framework by engaging students in future-oriented thinking and self-reflection of their possible selves as an engineer. This is done by asking students about their personal role as an engineer, what they expect to be doing in 10 years' time, and what they hope to have achieved by then.

3.4 Stage theory

Stage theory is a concept developed in developmental psychology which proposes that there are individual differences in the rate of development through stages, as well as the final stage attained. Transition between these stages is gradual and different for each stage of development (Learner, 1976). Applied to this study, it is expected that the perceptions of engineering and the understanding of the role of engineers will change as the student matures in age and education. This particular study includes students in their final two years of secondary school (Year 11 and 12), and is compared with the results of a study conducted over the same period of time using a very similar methodology which includes students enrolled in all years of an undergraduate engineering degree.

4. Methodology

4.1 Setting and Population

The data for this study was obtained using an anonymous online survey instrument that aimed to elicit personal narratives from students regarding their perceptions of the engineering profession, themselves, and their future career. A variety of public, independent, Boys', Girls', co-educational and selective schools in New South Wales were identified and invited by email and telephone communication to participate in the study in mid-Term 3 (late August). An offline version of the survey instrument, a letter to the Principal, and separate Information Statements directed at the school, parents and students were reviewed by the school before accepting the invitation to participate. Of the 90 schools contacted and invited to participate (67 independent and 23 public), a total of 10 schools accepted the initial invitation and had the surveys distributed to them via email with further instructions on administering the survey to students. There was no maximum or minimum limit placed on the number of responses from each school as the survey was voluntary, and each school returned a different number of responses based on the number of students who were willing to participate. The participating schools fit into the following categories:

1. Selective Public School in Metropolitan Sydney (n=1)
2. Boys' Independent School in Metropolitan Sydney (n=1)
3. Girl's Independent School in Metropolitan Sydney (n=1)
4. Co-educational Independent School in Metropolitan Sydney (n=3)
5. Co-educational Independent School in Regional or Rural New South Wales (n=4)

Teachers and careers advisors were asked to distribute the online survey to students in Year 11 and 12 (age 16-18) who are currently studying any level of Stage 6 Mathematics (Standard through to Extension 2), Physics, Chemistry, Biology, or Engineering Studies, as these students were identified as those who are most likely to have an interest in engineering and a motivation to pursue tertiary engineering education. The participating schools were given the option of allowing students to conduct the survey at home or in class. Six of the participating schools conducted the survey during class and four of the participating schools distributed the survey to relevant students by email or an online learning platform to be completed from home.

A total of 210 responses were obtained over a period of 4 weeks. 53 of the responses were discarded due to students submitting the survey without providing responses to the questions or providing inappropriate or extraneous responses, leaving 157 useful responses that could be analysed. Of these 157 participants, 63 of them were male (40%), 93 of them were female (60%), and one participant chose not to disclose their gender. All participants were in their final two years of secondary schooling, with 111 participants (71%) in Year 11 and 46 participants (29%) in Year

12. The greater number of Year 11 students is a result of the survey being administered during Trial Higher School Certificate (HSC) exams and approaching Year 12 graduation at the end of the term.

114 participants (73%) were from independent schools and 43 participants (27%) were from a selective public school. A total of 25 languages were spoken among the participants, with English being the most common language (spoken by all participants) followed by Chinese Mandarin (13%) and Korean (5%).

4.2 The Instrument

The survey commenced with screening questions to identify demographic data that could be used to analyse and provide context and insight to the survey questions. The screening questions related to the following:

- Gender
- The type of school the student is currently attending (Public, Independent, Boys', Girls' etc.)
- If any languages other than English are spoken at home
- Current year level at school (i.e. Year 11 or 12)
- Current subject enrolments
- If the student has a close friend or relative who is an engineer
- Which field of engineering the student is most interested in (e.g. Civil, Biomedical, No preference etc.)
- If the student is interested in a career in engineering (Definitely Yes, Probably Yes, Maybe, Probably Not, or Definitely Not)
- How long they have been interested in engineering (asked only to students who indicated an interest in a career in engineering, i.e. Definitely Yes, Probably Yes, or Maybe.)

The body questions of the survey were based on existing research conducted by Bennett and Male (2016) in their article published 'An Australian Study of Possible Selves Perceived by Undergraduate Engineering Students.' Bennett and Male's research was conducted in Perth among second- and third-year undergraduate engineering students, and the questions used from their study were mostly replicated with some minor adjustments to target senior secondary school students in New South Wales. Changes included making the first question more specific by including the word 'characteristics' rather than simply asking what an engineer looks like, and pluralising the word 'roles' in the third question to avoid potentially limiting the number of answers given by participants. The survey questions were chosen due to their applicability to the objectives of this research. One of the principal researchers and authors, Dr Sally Male, was contacted to seek guidance in using these questions as a replication study. Advice was received regarding the differing context and the way in which the survey was being administered. This led to minor variations being made to the survey questions used in the original study as well as the addition of screening questions. The survey questions used for this study were:

1. What are the characteristics of an ______ engineer? (Blank was filled with the participants' preferred discipline of engineering as identified in the screening questions).
2. What differences are there (if any) between the above characteristics and you as a person?
3. What do you see as the role of an engineer?
4. What will your personal role be?
5. How will the learning in ______ contribute to your development as an engineer? (Blank was filled with the participants' current subject enrolments as identified in the screening questions).
6. Imagine yourself in 10 years' time.
   a. What will you be doing?
   b. In a sentence, describe what you dream you will have achieved as an engineer over this time.

The survey was designed to take 10-15 minutes to complete, and all questions throughout the survey were voluntary, allowing the participant to withdraw at any time. The participants were asked to write as much as they could, with no restrictions placed on the length of each response. A small-scale pilot study was conducted with tertiary engineering students to ensure the survey questions were understood and interpreted by the respondents as expected.

A survey instrument was selected as the primary method of data collection to provide an effective means of obtaining a significant number of responses in a limited period of time. The number of surveys required to gain a broad understanding of engineering perceptions would have been difficult using interviews alone and would more likely be accomplished using a survey instrument. Likewise, obtaining interview responses would have been difficult given the current circumstances surrounding COVID-19 and social distancing requirements in schools. Interviews would also eliminate the ability to conduct the research anonymously, which is an important factor of consideration in conducting research on minors. An investigation of possible methodologies was conducted by referring to similar existing research. A table of strengths and weaknesses of all proposed and considered methodologies is provided in Appendix A.

4.3 Ethical Considerations

Thorough consideration was given to the ethical concerns and requirements of the research due to the involvement of minors (under the age of 18). The National Statement on Ethical Conduct in Human Research (2007) and Ethical Research Involving Children (Graham et al., 2013) were referred to, ensuring all ethical requirements were met. The research proposal and survey instrument were submitted for review by the University of Sydney Human Research Ethics Committee (HREC) and the NSW State Education Research Applications Process (SERAP). After multiple stages of review, all feedback from each Committee was addressed the research proposal and survey instrument were granted ethics approval to commence.

Parental Consent was required by SERAP for student participation in public schools. An Information Statement was provided which outlined the research and gave parents or guardians the choice to opt-out of the research. Responsibility was given to the school to manage consent forms. Independent schools were under no obligation to obtain parental consent, and the decision was left to them to determine whether or not this was required in their school. Anonymity was required by both HREC and SERAP and was realised by using an anonymous survey link that did not record personal data or geographical location. Some students recorded their email address at the end of the survey to request feedback, but these email addresses were removed and hidden during the data analysis to avoid association.

4.4 Data Analysis

A Qualitative Thematic Analysis was undertaken according to the process given by Braun and Clarke (2006). All survey responses were compiled and grouped into questions, then reviewed latently by reading them and generating initial codes. These codes were then sorted into emergent themes, and the data was reviewed according to these themes. Different themes were identified for each question and are defined in Appendix B.

Each individual response was then re-read and analysed latently. The occurrence of each theme in the responses were tallied using Microsoft Excel and converted to percentages to determine the frequency of each theme (Bree & Gallagher, 2016). This process was repeated three times to ensure responses or themes within responses were not missed and that the final tallies were accurate.

5. Findings and Analysis

5.1 Survey Screening Questions

5.1.1 Subject Enrolment

The subject enrolments of participants at the time of the survey is shown in Table 5.1. Only the highest level of Mathematics was counted, for example, if the participant was currently studying Extension 1 Mathematics and Advanced Mathematics, the participant was counted only once as studying Extension 1 Mathematics. Of the 153 participants who specified which subjects they were enrolled in, 100% of them did some level of mathematics, and 76% of them did at least one discipline of science.

Table 5.1 – Subject Enrolment Results

Subject	Number of Participants	Percentage
Mathematics Extension 1 or 2	75	48%
Mathematics Advanced	35	22%
Mathematics Standard	43	27%
Physics	55	35%
Chemistry	69	44%
Biology	89	57%
Engineering Studies	6	4%
Did not specify	4	3%

5.1.2 Relative or Close Friends in Engineering

Participants were asked if they have a close friend, relative, or personally know someone who is an engineer. Of the 157 responses obtained, 83 participants (53%) stated that they knew an engineer, while 74 participants (47%) stated that they did not know an engineer. This variable was considered in the analysis of some of the following questions.

5.1.3 Interest in a Career in Engineering

Participants were asked “Are you interested in a career in engineering?” and given the options of Definitely Yes, Probably Yes, Maybe, Probably Not, or Definitely Not. Of the 157 responses obtained, only 1 student did not specify their interest. These responses were analysed according to gender, as shown in Figure 5.1, and in terms of whether the participant had a relative or close friend who is an engineer, as shown in Figure 5.2.

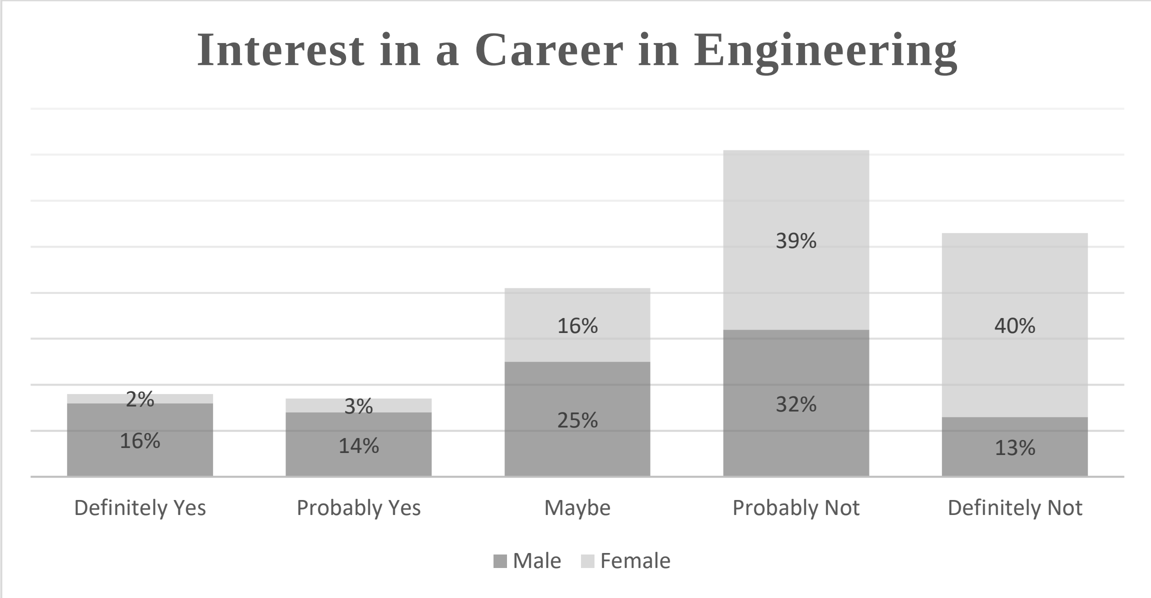

Figure 5.1 - Interest in a Career in Engineering (Male vs. Female)

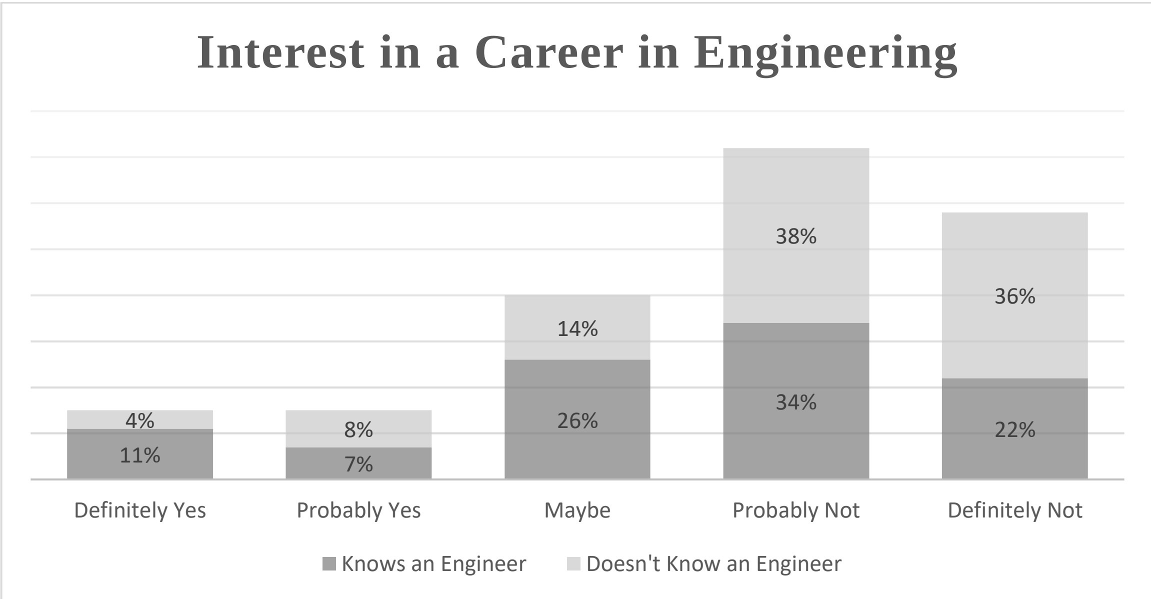

Figure 5.2 - Interest in a Career in Engineering (Association with a Professional Engineer)

Participants were considered as having an interest in a career in engineering if they selected Definitely Yes, Probably Yes, or Maybe. Of the 55 participants who had an interest in a career in engineering, 20 (37%) had been interested for less than a year, 16 (30%) had been interested for 1 to 2 years, and 18 (33%) had been interested for more than 2 years.

5.1.4 Preferred Engineering Discipline

Participants were given a list of engineering disciplines commonly offered by major Australian universities and asked to select which field of engineering they were most interested in. The results of this question are shown in Table 5.2 and Figure 5.3 according to preference by males and females. Note that one student did not indicate their gender but selected mechanical engineering as their preference.

Table 5.2 – Preferred Discipline of Engineering (Male vs. Female)

	General (n=157)		Male (n=63)		Female (n=93)	
Preferred Discipline	**No. of Responses**	**Percentage**	**No. of Responses**	**Percentage**	**No. of Responses**	**Percentage**
No preference	67	43%	14	22%	53	57%
Biomedical	30	19%	10	16%	20	22%
Mechanical	12	8%	10	16%	1	1%
Software	11	7%	8	13%	3	3%
Civil	10	6%	6	10%	4	4%
Aeronautical	9	6%	6	10%	3	3%
Chemical	8	5%	3	5%	5	5%
Mechatronic	6	4%	3	5%	3	3%
Electrical	4	3%	3	5%	1	1%

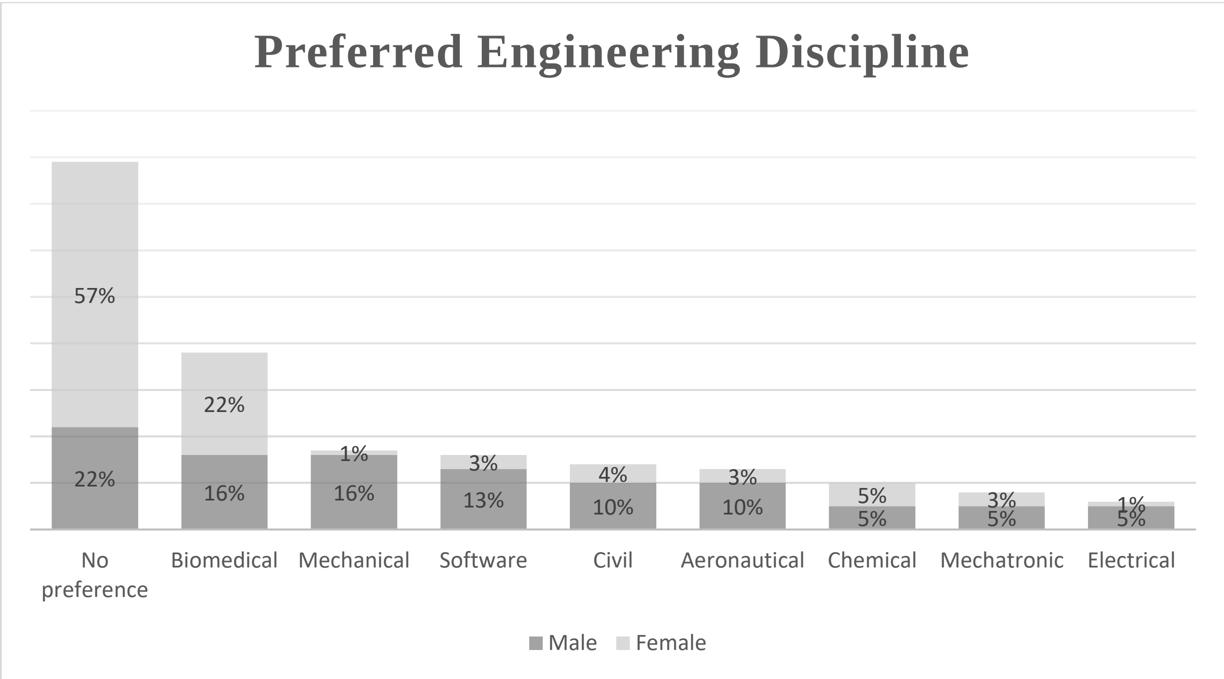

Figure 5.3 – Preferred Engineering Discipline (Male vs. Female)

5.2 Survey Body Questions

5.2.1 Q1. What are the characteristics of a _______ engineer?

Based on the participants' response regarding their preferred engineering discipline, they were then asked to consider the characteristics of that engineer. The survey instrument automatically prefilled the blank section of the question based on their previous response. If the participant had no preference of engineering discipline, they were asked to consider the characteristics of an engineer in general. Responses were most often in the form of a list containing one or more characteristics. The most common results for this question are shown in Table 5.3, with a more detailed analysis shown in appendix C1. The themes are shown in order of decreasing general occurrence.

Table 5.3 – Characteristics of Engineers (Q1) Results

	Male (n=63)		**Female (n=93)**		**Unk (n=1)**	**Total (n=157)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Technical Knowledge / Skills	26	41%	27	29%	0	53	34%
Problem Solving	22	35%	28	30%	0	50	32%
Maths / Science Ability	11	17%	27	29%	0	38	24%
Creative / Innovative	13	21%	21	23%	0	34	22%
Smart / Intelligent	9	14%	17	18%	0	26	17%
Unsure	9	14%	15	16%	0	24	15%
Critical / Analytical	9	14%	13	14%	0	22	14%
Communication Skills	9	14%	13	14%	0	22	14%
Teamwork	6	10%	10	11%	0	16	10%
Practical	6	10%	9	10%	0	15	10%

Responses varied depending on the participant’s preferred engineering discipline, however no generalisations will be made due to the non-representative sample sizes of the individual disciplines. Nevertheless, some trends emerged which are worth mentioning. For example, 24% of participants who had no preferred discipline said they were unsure of the characteristics of an engineer compared to 9% of participants that did have a preferred discipline.

When considering the effect of knowing an engineer on the perceived characteristics, 10% of participants who knew an engineer said they were unsure of the characteristics of an engineer, while 22% of participants who did not know an engineer were unsure of the characteristics. Participants who knew an engineer were also more likely to identify technical knowledge and skills as a characteristic of an engineer.

5.2.2 Q2. What differences are there (if any) between the above characteristics and you as a person?

The next question was asked to understand the participants self-efficacy based on their perceptions of the characteristics of an engineer, giving them the opportunity to make comparisons and identify what factors they feel may be preventing them from pursuing a career in engineering. Mostly the same themes were used from the previous question, as students tended to select one or more of the characteristics they had previously identified and applied it to themselves. This allowed for ease of comparison with the previous question and presented some clear trends. Two additional themes emerged, including “Not interested/passionate” and “None”. The response “None” implies that the participant believed that there are no differences between the characteristics of an engineer and themselves as a person. The most common results for this question are shown in Table 5.4, with a more detailed analysis shown in appendix C2. The themes are shown in order of decreasing general occurrence.

Table 5.4 – Difference in Characteristics (Q2) Results

	Male (n=63)		**Female (n=93)**		**Unk (n=1)**	**Total (n=157)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
None	23	37%	19	20%	0	42	27%
Unsure	15	24%	21	23%	0	36	23%
Technical Knowledge / Skills	7	11%	9	10%	0	16	10%
Maths / Science Ability	3	5%	10	11%	0	13	8%
Creative / Innovative	3	5%	9	10%	0	12	8%
Not interested / passionate	2	3%	10	11%	0	12	8%
Problem Solving	2	3%	7	8%	0	9	6%
Communication Skills	2	3%	7	8%	0	9	6%

Males were more likely to believe that there was no difference between the characteristics of an engineer and themselves, with 37% of males stating that there was no difference compared to 20% of females. 50% of participants indicated that they were either unsure of the differences or that there were no differences. Among the most common differences identified by both males and females were technical knowledge and skills, and maths/science ability.

Considering students who believed there was no difference between the characteristics of an engineer and themselves, association with an engineer did not make a significant difference, with 29% of participants who knew an engineer saying there was no difference compared to 24% of participants who did not know an engineer. However, as expected from the results of the previous question, students who knew an engineer were less likely to say they were unsure of any differences (14% compared to 32%). Participants who did not know an engineer were also less likely to consider maths/science ability as a difference (14% compared to 1%).

There was also a correlation between participants interest in engineering and their perceptions of the differences between themselves and the characteristics of an engineer, with 48% of interested participants (selected definitely yes, probably yes, or maybe in the screening question) perceiving no differences, while 18% of uninterested participants (selected probably not or definitely not) perceiving no differences between themselves and the characteristics of an engineer.

5.2.3 Q3. What do you see as the roles of an engineer?

Another goal of this research was to capture what secondary school students perceive as the role or responsibilities of an engineer. The most common results for this question are shown in Table 5.5, with a more detailed analysis shown in appendix C3. The themes are shown in order of decreasing general occurrence.

Table 5.5 – Roles of an Engineer (Q3) Results

	Male (n=63)		**Female (n=93)**		**Unk (n=1)**	**Total (n=157)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Create / Make	10	16%	31	33%	1	42	27%
Design	14	22%	20	22%	0	34	22%
Improve / Advance / Develop	12	19%	21	23%	1	34	22%
Build / Construct	9	14%	24	26%	0	33	21%
Solve	18	29%	12	13%	0	30	19%
Help People / Society / World	8	13%	19	20%	0	27	17%
Unsure	14	22%	12	13%	0	26	17%
Using Technology / Computer	11	17%	12	13%	0	23	15%
Innovate	5	8%	10	11%	0	15	10%

Most students, regardless of whether or not they had selected a preferred discipline, gave broad and generic terms when describing the roles of an engineer, such as:

"To design solutions to solve problems."

"To fix stuff and make stuff. To come up with new advancements in stuff."

"They design and look into constructing new technology."

Some students, however, were able to provide more specific details of the roles of an engineer, including:

"Design medical equipment, manufacture artificial organs, applying engineering and design concepts to medicine and biology." (Referring to Biomedical Engineering).

"Working in the field to conduct experiments, such as soil samples. Analysing data and drawing conclusions. Planning projects, such as bridges or buildings." (Referring to Civil Engineering).

As most of the responses were written in generic terms, there were no significant differences or patterns worth mentioning between the preferred disciplines selected by participants. Worth mentioning, however, are the differences in responses between males and females, as shown in Table 5.5. For example, females were more likely to mention terms such as "create" / "make" or "build" / "construct" while males were more likely to mention terms such as "solve." Also worth mentioning is the effect of an association with an engineer, with 10% of participants who knew an engineer saying they were unsure of the roles, and 24% of participants who did not know an engineer saying they were unsure. Similarly, students who knew an engineer were more likely to reference terms such as "design" (31% compared to 11%).

5.2.4 Q4. What will your personal role be?

Students who indicated that they were interested in engineering in the screening questions (Definitely Yes, Probably Yes, Maybe) were asked to consider their personal role as an engineer. The aim of this question was to engage participants in future-oriented thinking and self-reflection of their possible selves as an engineer. The most common results for this question are shown in Table 5.6, with a more detailed analysis shown in appendix C4. The themes are shown in order of decreasing general occurrence.

Table 5.6 – Personal Role as an Engineer (Q4) Results

	Male (n=35)		**Female (n=19)**		**Unk (n=1)**	**Total (n=55)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Unsure	7	20%	6	32%	0	13	24%
Technical Engineering Work	10	29%	2	11%	0	12	22%
Improve the World / Society	8	23%	2	11%	0	10	18%
New Ideas / Innovate	6	17%	2	11%	0	8	15%
Teamwork	4	11%	2	11%	1	7	13%
Design	3	9%	3	16%	0	6	11%

Due to the smaller sample size in this question, generalisations cannot be made regarding the differences between preferred disciplines and association with an engineer. However, a notable finding is that despite expressing an interest in pursuing a career in engineering, almost one-quarter (24%) of respondents were unsure of what their personal role as an engineer would be. This was especially the case for females (32% compared to 20% of males). Other trends emerged between genders, with males more likely to see their personal role involving technical engineering work (29% compared to 11% of females), and only females explicitly mentioning leadership, for example:

"I imagine designing circuits and code as a mechatronic engineer..." (Male)

"A team leader, or the person who is in control for making the final decisions and someone who they can all turn to for support." (Female)

Many participants drew on previous experiences to guide their response, such as school programs or hobbies:

"I have participated in the Science and Engineering Challenge with my school that allowed me to construct a bridge to carry weights. I very much enjoyed this activity and believe my personal role would involve building models and testing them."

"I believe I am a more creative person and I would probably enjoy designing and creating products using technologies such as 3D printing as I have previously done this at school and enjoyed the process very much."

This link between participant's broader passions and engineering gives some insight into their motivational drivers and reasons for pursuing the profession. This idea of intrinsic motivation was also found by Bennett and Male (2016) and may be a key component to addressing attrition. This also provides an insight into the role that schools can play in developing an interest in engineering among students, with multiple participants mentioning experiences they have had at school.

5.2.5 Q5. How will the learning in _______ contribute to your development as an engineer?

Based on the participants' response regarding their current subject enrolments, they were then asked to consider how the learning in these subjects would contribute to their development as an engineer. The survey instrument automatically prefilled the blank section of the question based on their previous response in the screening question. This question was asked to all participants with the aim of understanding if students, whether they are interested in engineering or not, are able to recognise the relevance of the content they are learning in mathematics/science courses in relation to STEM professions such as engineering. The most common results for this question are shown in Table

5.7, with a more detailed analysis shown in appendix C5. The themes are shown in order of decreasing general occurrence.

Table 5.7 – Learning in Currently Enrolled Subjects (Q5) Results

	Male (n=63)		**Female (n=93)**		**Unk (n=1)**	**Total (n=157)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Technical Skills / Calculations	18	29%	34	37%	1	53	34%
Knowledge of the Field	27	43%	22	24%	0	49	31%
Unsure	10	16%	22	24%	0	32	20%
Engineering Thinking	12	19%	12	13%	0	24	15%
Don't want to be an engineer / It won't	6	10%	10	11%	0	16	10%

65% of participants were able to identify a connection between the learning in mathematics/science courses and technical skills/calculations or knowledge of the engineering field. For example:

"…by applying the knowledge I have learnt in these courses I could then tackle real life situations for example using mathematics and physics I could work out the optimal way to achieve something for example what length of wood would be the strongest."

"I now have good ground knowledge on the required information required to do Mechatronic Engineering."

Some participants (15%) also mentioned how the subjects will help them to develop a way of thinking that is conducive with success as an engineer, for example:

"The learning in these subjects will enhance and develop my abilities and understanding of maths and the properties of the world we live in, helping me to develop an engineer's mindset."

"I believe learning mathematics and science will be able to help me significantly as it is required to be able to model, analyse, and solve problems."

"These subjects will help me have a smart and critical outlook, to make sure to double-check any solutions to get the best outcome."

However, 20% of students were unsure of how their current learning has relevance to engineering, and a further 10% of participants said that they were not interested in engineering, and therefore the learning in their current subjects will not contribute to their development as an engineer. This represents almost one-third of participants either failing to, or simply choosing not to recognise the connection between their current learning and engineering. This may be due to the lack of understanding of the roles of an engineer as outlined previously, or simply rejecting the idea that their current learning can be of benefit to them as they have no intention of using it in an engineering context in their future career. Examples include:

"I do not want to be an engineer so it will not necessarily help me to become an engineer."

"My learning in these subjects will not contribute to my development as an engineer because I am not passionate in the engineering field."

5.2.6 Q6. Imagine yourself in 10 years' time.

5.2.6.1 (a). What will you be doing?

Based on the framework of Possible Selves, students were asked to consider what they will be doing in 10 years' time with the aim of understanding what they hope or expect to become. This question was asked to all participants regardless of their interest in engineering. The most common results for this question are shown in Table 5.8, with a more detailed analysis shown in appendix C6. The themes are shown in order of decreasing general occurrence.

Table 5.8 – Doing in 10 Years (Q6a) Results

	Male (n=63)		**Female (n=93)**		**Unk (n=1)**	**Total (n=157)**	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Non-engineering related work	27	43%	55	59%	0	82	52%
Engineering related work	15	24%	8	9%	1	24	15%
Unsure	12	19%	11	12%	0	23	15%
Non-work related	6	10%	17	18%	0	23	15%
General Work	7	11%	11	12%	0	18	11%

With 64% of participants indicating that they were probably not or definitely not interested in a career in engineering in the screening questions, it was not surprising that over half of participants (52%) expect to be in a non-engineering related profession in 10 years' time. Of these 52%, many participants mentioned a role in health care or medicine, such as becoming a doctor, nurse, or physiotherapist. A wide range of other professions were mentioned, in fields such as law, finance, education, social work, and entrepreneurship. This is in contrast to the 15% of participants who expect to be in an engineering-related role in 10 years, and a further 15% of students who are unsure.

5.2.6.2 (b). In a sentence, describe what you dream you will have achieved as an engineer over this time.

Participants who had previously expressed interest in a career in engineering in the screening questions were then asked what they hope they will have achieved as an engineer over this time, with the aim of further understanding the theory of Possible Selves and how it applies to prospective engineering students. The most common results for this question are shown in Table 5.9, with a more detailed analysis shown in appendix C7. The themes are shown in order of decreasing general occurrence.

Table 5.9 – Achieved as an Engineering (Q6b) Results

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Significant Projects / Problems Solved	16	46%	10	53%	0	26	47%
Unsure	7	20%	7	37%	0	14	25%
Impact on the World	6	17%	3	16%	0	9	16%
Impact on Others	2	6%	4	21%	0	6	11%
Career Satisfaction	4	11%	1	5%	1	6	11%

Considerably higher than any other theme was that of working on significant projects or solving significant problems, with 47% of participants mentioning this as a key achievement of theirs in the next 10 years. Many of these responses are seemingly optimistic and reflect the positive self-efficacy of some participants who believe they will be able to make significant, often wide-reaching impacts early in their engineering career. Examples include:

"Hopefully would have completed several successful public engineering projects - construction of new roads/public buildings."

"To create a machine that produces energy so efficiently that we would not need to be concerned over the damage to the environment and/or the reliability of the machine."

"I will have been part of a team that has made an impactful new discovery/development on some form of medical technology that has in turn been used to save lives."

5.3 Summary of Results Among University Students

This study was conducted as a joint Honours thesis with another engineering student who applied the same approach to engineering students at the University of Sydney. The study, titled 'Perceptions of Engineering Among University Students', used a similar survey instrument with some minor changes to suit the audience. A total of 28 responses were obtained and interviews were conducted with 4 of these participants. A summary of the participants and their engineering major is outlined in Table 5.10. Note that '1stY' is an abbreviation of 'First Year' engineering students, and 'FY' of 'Final Year' students (fourth or fifth year).

Table 5.10 – Summary of University Participants

Major	M (12)	F (15)	Unk (1)	1stY (4)	2ndY (7)	3rdY (6)	FY (11)
Aeronautical (3)	1	2	0	0	2	0	1
Civil (12)	4	8	0	2	0	6	4
Environmental (1)	1	0	0	0	0	0	1
Mechanical (1)	1	0	0	1	0	0	0
Mechatronic (2)	1	1	0	1	1	0	0
Combined (9)	4	4	1	0	4	0	5

When asked if they were interested in a career in engineering, no participants selected 'Probably Not' or 'Definitely Not'. Three-quarters of students stated that they have a close friend or relative who is an engineer. A summary of these results is shown in Table 5.11.

Table 5.11 – Interest in Engineering Career and Knowing and Engineer (University Participants)

Interest in Engineering	M (12)	F (15)	1stY (4)	2ndY (7)	3rdY (6)	FY (11)	Total (28)	Knows an Engineer (21)
Definitely Yes	5	9	2	3	4	6	15 (56%)	10 (67%)
Probably Yes	6	2	2	2	2	2	8 (30%)	6 (75%)
Maybe	1	4	0	2	0	3	5 (19%)	5 (100%)

Regarding the characteristics of an engineer, the most common responses were problem solving (57%), teamwork/interpersonal skills (29%), communication (25%), technical skills (21%) and creativity (21%).

Responses were less consistent when asked if there are any differences between themselves and the characteristics of an engineer, with the most common responses being creativity/innovation (25%), none (14%), technical knowledge/skills (14%), and communication/interpersonal skills (14%).

In response to ‘What do you see as the roles of an engineer?’, the most common responses were design (46%), solve problems (39%), project management (29%), create/make (25%), build/construct (18%), and help people/society/world (18%).

When asked to imagine their personal role as an engineer, participants mostly responded with project management (33%), design (26%), innovate (15%), research (15%) and calculations (15%). Only one student (final year) indicated that they were not sure.

Participants were asked how the learning in their university degree would contribute to their development as an engineer. The most common responses were technical skills/calculations (50%), engineering thinking (43%), and knowledge of the field (29%). Inconsistency in responses was found between year groups, as 75% of responses regarding engineering thinking came from final year students, and none from first year students. Also, 18% of participants (80% of which were final year students) stated that the learning at university is insufficient in preparing them to be an engineer.

Finally, when asked to consider what they will be doing in 10 years from now, the most common response was engineering-related work (78%), of which all final year students indicated. The remaining 22% indicated that they would be doing non-engineering work. When considering what they will have accomplished as an engineer, participants shared their goals of working on significant projects/problems (30%), improving the world/future (30%), and helping others (26%).

6. Discussion

It is certainly not implied that the findings of this research are representative of the senior secondary school population, however, similar findings are reflected in numerous previous studies, which provides strong validation of the data presented here. Multiple theoretical frameworks, including conceptual ecology, threshold concepts, possible selves, and stage theory (each outlined in Section 3), were used as a basis for this research. As the survey instrument explored various concepts and ideas, the use of multiple frameworks provided several avenues of interpretation of the results. When analysed through the lens of these frameworks, the results may provide insights into thought patterns and perceptions among senior secondary students regarding their understanding of engineering and their future aspirations.

6.1 Misperception Compared to a Lack of Perception

The aim of this research was to understand the perceptions, or possibly the misperceptions, of engineering among senior secondary school students. What was not expected was the prevalence of a lack of perception of engineering, indicated by a considerable number of students who mentioned they were unsure of an answer to several questions. This is consistent with Fralick et al. (2009) who found that middle school students in the United States commonly have a lack of conception relating to engineering rather than a misconception. This implies that students, especially those who indicated that they are not interested in engineering, may be basing their interest on a lack of awareness of what engineering is, and therefore do not have the opportunity or resources to develop an interest in the field. This can have adverse consequences for the recruitment efforts of universities, as many capable and motivated students may simply be unaware of the opportunities that exist in engineering and therefore never pursue the profession.

The conceptual ecology framework would imply that misconceptions are "deeply held beliefs that interfere with learning and are resistant to change" (Montfort et al. 2013), however, it should not be assumed that accurate perceptions would therefore be easier to develop among students with a lack of perception. In fact, building on existing ideas may be beneficial when educating students about engineering as it forms associations with what the student already knows and allows them to understand the role that engineering plays within their own context (Montfort et al., 2013). Where possible, it would be beneficial for educators to consider students' prior understanding of engineering and how it relates to their wider context, as this provides an opportunity to correct misperceptions or create new perceptions in a way that will make sense and have significance to students. For example, considering the dominant engineering industries or projects within the region of the educational institution or students' homes will be more relevant to students and allow accurate perceptions of engineering to be developed, rather than presenting it as an abstract field or profession with which students cannot relate or identify.

Meyer and Land (2003) describe threshold concepts as a portal which opens a “new and previously inaccessible way of thinking about something”, and which allows a learner to progress once an understanding is obtained. However, they also identify that these concepts are often troublesome, and many students may fail to grasp or understand them. As identified by Parkinson (2011), one such threshold concept is the ‘role of engineers’. Of concern, then, is the finding that almost one in five students were unsure of the roles of engineers. Whether this is because the concept is troublesome, or students are simply not exposed to engineering enough in school, society or through the media to develop a perception, is yet to be determined. As a threshold concept, it is necessary that students, particularly those who wish to pursue engineering as a profession, develop an understanding of the roles of an engineer. Misalignment between the perceived roles of an engineer and sense of self may result in attrition or dissatisfaction, particularly if students believe this misalignment is unresolvable (Bennett and Male, 2016). Therefore, it is ideal for students to develop an accurate perception before commencing tertiary education to minimise the likelihood of attrition or dissatisfaction. Similarly, participants’ limited perception of what engineers do may deter them from studying engineering due to a lack of knowledge of the potential opportunities within the profession. This can result in individuals missing out on a career that they may be well-suited to, and the industry missing out on creative and competent engineers.

The theoretical framework of ‘possible selves’ refers to an individuals’ projections about what they hope or expect to become, combining cognitive manifestations with the present self, leading to motivation to realise or avoid the projected persona (Markus and Nurius, 1986; Schnare et al. 2012; Bennett and Male, 2016). This framework was explored in this study by asking students to visualise their possible self, including their personal future role as an engineer and what they hope to accomplish as an engineer in 10 years. When considering their personal role as an engineer, or what they hope to accomplish in the next 10 years, a lack of perception was once again identified, with one in four students being unable to respond despite indicating that they were interested in a career in engineering. This finding implies that while some students may have a desire to be an engineer, they may also be unaware of the reality of the profession and what they will be doing as an engineer. This appears to have negative implications on students’ ability to imagine their possible self and thus develop the motivation required to realise their future as an engineer. This may be due to a lack of understanding of the role of engineers, which once an understanding is obtained, will be transformative for students in helping them realise their career aspirations.

6.2 The Effect of Knowing an Engineer

Godwin et al. (2014) identified that there is a strong familial influence on engineering as a career choice, especially among students whose fathers are engineers that also play an influential role in determining their child's career choice. Such students are over 3 times more likely to choose a career in engineering, partly because they are able to see an individual they know within the profession and obtain an understanding of their role and witness their accomplishments. Within the conceptual ecology framework, this provides students with an opportunity to develop a conceptual understanding of engineering. From this understanding, students may be able to determine their ability to perform within the profession (i.e. self-efficacy), thus allowing them to imagine themselves within the profession and realise their possible self. In this study, students who knew an engineer were almost twice as likely to express that they were interested in a career in engineering and less likely to indicate that they were 'Definitely Not' interested. However, students' responses to knowing an engineer were based on their understanding or perception of what an engineer is and therefore may not realistically indicate that they know an engineer. Nevertheless, this finding suggests that students, in general, are more likely to be interested in engineering if they have an association with a professional engineer.

Similarly, students who knew an engineer were less likely to be unsure of responses to questions, particularly when asked about the roles of an engineer. This implies that one way to increase students understanding of this threshold concept is through exposure to, and interaction with, professional engineers. This is consistent with Bevins et al. (2005), who found that students believed they could benefit from having engineers visit their school and act as positive role models to provide career advice and direction, and Darby et al. (2003) who found that students construct their own image of an engineer based on personal contact with engineers or people who share with them what engineers do, such as parents, relatives and teachers. Overall, the lack of recognisable role models appears to have a negative effect on students' understanding of engineering and their desire to pursue it as a career.

6.3 Differing Perceptions Among Genders

Engineering has been identified as one of the most gender stereotyped occupations (White and White, 2006), commonly perceived as being a profession for males. This is reflected within Australian industry and universities, with approximately 17% of engineering undergraduates each year identifying as female (AECD, 2019). These notions were supported by the findings in this study, revealing that males are more likely to be interested in a career in engineering and are able to imagine themselves within the profession more easily than females. Gender disparity was prevalent among engineering disciplines as well, with females more likely to be interested in biomedical or chemical engineering, and males tending to prefer all other disciplines, particularly mechanical, civil and software engineering, a trend that is consistent with the Statistical Overview of the Engineering Profession (Kaspura, 2019).

While the characteristics of engineers were generally perceived similarly among males and females, there was some variation in perceived differences between their own characteristics and those of an engineer. This was most noticeable among males, who were more likely to say that there are no differences between their own characteristics and those of an engineer. This may reflect a difference in self-efficacy between males and females, with females also indicating that a common difference between themselves and an engineer is their ability to perform well in mathematics and science. Conversely, however, males were more likely to be unsure of the roles of engineers and were more likely to respond with generic terms such as “solve”, compared to females who spoke of creating, making, building and constructing. This may imply that although males appear more confident about their ability to perform successfully in engineering, this confidence may be based simply on alternate perceptions between males and females regarding the threshold concept of the role of engineers. According to the threshold concepts framework, when the role of engineers is understood, a more holistic understanding and greater meaning of the study of engineering can be developed. This finding shows that perhaps, due to the broader, or more holistic understanding females have of the roles of engineers, they become more realistic about their own abilities and how they might perform as an engineer, thus suggesting that threshold concepts have an explicit effect on self-efficacy and thus students’ projections of their possible selves.

When considering their possible selves, females were more likely to be unsure of what their career in engineering would look like. Of the females who could imagine their personal role as an engineer, they were more likely to mention design, research, and leadership, while males were more likely to mentioned technical roles. Concern regarding the uncertainty among females of how they fit into a male-dominated industry and the existence of inequality among genders has been expressed by Frehill (2013) and Fouad et al. (2017), who found that women were less likely to persist in an engineering career. Female engineers may bring valuable skills to the profession, however, the inability to imagine one’s possible self within the profession may present a significant barrier for entering and persisting in engineering. In this study, only one student (female) explicitly mentioned that engineering is for males. No mention was made otherwise about gender dominance in engineering. However, the results indicate that there may exist an underlying thought pattern that engineering is for males, with males expressing greater interest in a career in engineering, being more likely to perceive no differences between themselves and the characteristics of an engineer, and females expressing greater uncertainty of their personal role as an engineer or what they will accomplish as an engineer.

Reasons for the differences in perceptions of engineering between males and females may include the distribution of information from schools and universities to particular audiences (i.e. males), a lack of recognisable female engineers portrayed in the media, and the view of engineering being a male-dominated industry (Darby et al. 2003). Australian universities and institutions appear to be making an effort to reduce this gender disparity by increasing female engineering programs, including scholarships, outreach initiatives, and societies. These efforts are having a positive, albeit gradual effect on the number of female students in engineering, with females making up 14.4% of undergraduate commencements in 2007 but increasing to 16.9% in 2017 (AECD, 2019).

6.4 The Influence of School Subjects on Engineering Perception

In this study, technical skills, problem solving, and mathematics were all considered necessary skills or characteristics of an engineer. However, very few students gave any examples of how mathematics was related to engineering, and simply stated that it was necessary. Likewise, although problem solving was mentioned frequently, there was little reference to what problems would be solved.

As expressed by the students in this study, and supported by previous research (Godwin et al., 2016, Pierrakos et al., 2009), mathematics and science ability were considered important characteristics for engineers, and considered a significant element of the role of an engineer. While this may be true in most cases, with engineering degrees and many engineering roles requiring an understanding and application of mathematical and scientific concepts, an issue arises when students are unable to make a realistic or accurate connection between mathematics/science and engineering. Since many students do not have a strong or accurate understanding of what engineering is, they tend to rely on analogies to similar fields that they are familiar with based on their conceptual understanding. In this case, students are familiar with mathematics and science since they are taught as compulsory subjects throughout the junior stages of secondary school, resulting in generalisations from these subjects being applied to what little understanding of engineering the student may have (Montfort et al. 2013). This relationship between engineering and related knowledge may result in strong associations between engineering and mathematics/science, making other perceptions of engineering unintelligible to students (Strike and Posner, 1992). For example, by placing such emphasis on mathematics and science without giving any regard to their application in engineering, students may not have enough experience with mathematics and science to understand how it could be used to solve real-world problems in engineering, or may lack motivation to find any connection between the disciplines.

This was also evidenced by the 20% of students (all of whom studied some level of mathematics) who were unsure of how their current learning would be beneficial in their development as an engineer, and a further 10% who explicitly stated that it won't contribute to their development as an engineer. Similar to the behaviour observed by Bennett and Male (2016), some students struggled to identify the relevance of their school subjects to their future careers, while others were able to find connections and relevance. While many engineers do not use high level mathematics in their daily tasks as engineers, mathematics is a significant component of tertiary engineering qualifications. Therefore, students may benefit from increased guidance and examples to understand the relevance of their learning to the roles of engineers and other professionals.

As stated in the 'Women in STEM Strategy' by Engineers Australia (2018):
"The message we deliver currently is to tell our students they need to study maths and science subjects, without helping them understand the 'why'. It is critical we put context around STEM skills as foundations for innovative thinking and real-world problem solving. Potentially this would present a challenge for a high percentage of teachers too. We need to invest to upskill our valuable teaching staff so they are informed and confident in communicating the 'why'."

Relevance between mathematics/science and engineering cannot be assumed by educators, and by establishing such relevance, students are more likely to be able to make vital connections between their possible self, their learning and their intended field of work (Bennett and Male, 2016). Consideration of such relevance should not be given only to technical skills such as mathematics and science, but also how students' current learning can develop their socio-technical skills for their career, for example, how research projects or working in teams may be beneficial outside of the classroom and in a professional setting.

6.5 The Influence of Engineering Perceptions on Career Choices

Nauta, Epperson, and Waggoner (1999) identified that perceptions of careers are often linked to whether students feel they have the ability to enter those careers. In other words, perception of one's ability within a role is equally as important in career selection and persistence as the perception of the role itself. Trevelyan (2011) suggests that engineering educators may be misleading students and encouraging misperceptions by emphasising technical roles and responsibilities over socio-technical roles. This may skew students' perception of their possible self, particularly those who feel their strengths are related to the socio-technical aspects of engineering rather than the technical aspects, and possibly defer them from pursuing a career in engineering. Similarly, it may result in technically minded students feeling dissatisfied upon realising the importance of socio-technical skills within their role as an engineer. This is evident in this study, as the highest-ranking perceived characteristics of engineers are based on the technical rather than the socio-technical aspects of the profession. However, Jocuns et al. (2008) found that although this scientific way of thinking is common among commencing undergraduate students, there tends to be a shift towards a more career-orientated way of thinking among graduating students which includes socio-technical skills.

Almost one in five students in this study mentioned that some form of altruism, whether regarding individuals, society, or the world, is a role of engineers. When referring to what they want to have accomplished in 10 years as an engineer, more than one-quarter of students referred to some form of altruism, and almost half of students mentioned their desire of working on a significant project or solving a significant problem. While altruism is a common reason for students to commence engineering degrees, this perception may be exaggerated or overly romantic for most students and tends to become less hopeful or exaggerated as the student progresses throughout their degree (Jocuns et al., 2008; Seymour and Hewitt, 1997; Pritchard and Mina, 2013).

Well-intentioned university websites and programs often make aspirational claims to attract students, such as learning to solve global problems by applying their technical skills or knowledge. This, as well as other influences such as career advisors, teachers, and outreach programs, may be contributing to the highly technical and altruistic perception of engineering that exists among senior secondary students. While this is a positive image that is likely to attract many students, there is the risk that they may not persist in their studies as they discover the realities or components of the profession that they did not previously know existed (Pritchard and Mina, 2013). It is more important that educators build on students' existing conceptual understanding of engineering to help them develop a realistic perception of the roles of engineers, rather than presenting a fantasised or romantic version.

6.6 Educating Students About Engineering

Senior secondary school students cannot be expected to understand or accurately perceive the field or profession of engineering alone. Given their age, most students have not had any meaningful exposure to engineering or an opportunity to develop a holistic conceptual understanding of the profession, despite being surrounded by the products and results of engineering in everyday life. Without the assistance of educators, students will continue to depend on their limited or inaccurate knowledge of the profession and make education and career choices based on that knowledge (Male and Bennett, 2015). As secondary school teachers are often no better informed about careers such as engineering, there is a need for further teacher education or external partners to provide guidance to students, particularly those who aspire to a career in engineering (Dawes and Rasmussen, 2007).

It is clear from this study that interest in engineering plays a role in students' perception of the profession, as the students who were unsure of many questions often did not have a preferred engineering discipline or expressed that they were not interested in a career in engineering. A matter of debate is whether educating students about engineering can lead to an increase in interest in an engineering career. As previously outlined, threshold concepts, when understood, can be highly motivating. Conversely, students tend to leave tertiary engineering studies if they feel it does not align with their sense of self. Thus, within the framework of possible selves, educating students in senior secondary school about engineering may have one of two effects; either increasing the number of students interested in engineering as their understanding broadens and they find commonalities between their strengths or values and the profession (i.e. students are inspired to move towards a 'possible self' within engineering), or a reduction in student interest as the realities of engineering become clearer to them (i.e. students' move away from a 'possible self' within engineering). Either way, early exposure is likely to have a positive effect, as students who enter tertiary engineering will have made their decision based on more accurate information rather than the limited knowledge or perceptions that they developed on their own (Douglas et al., 2004). Educators should be sure to provide a well-rounded, non-biased overview of many professions, not only engineering, and focus more on developing whatever career ambitions a student may have rather than using persuasion or coercion (Montfort et al. 2013). Understanding how students perceive engineering and how this perception can be changed based on their conceptual understanding is an important step to progress in this direction.

Douglas et al. (2004) and Bevins et al. (2005) identified ways for educators to improve engineering education in their classrooms. Although their findings apply to schools within the United States and the United Kingdom, similar practices may be used or are already being used in Australia. These include increasing hands-on or practical learning, adding a technological approach to lessons, integrating engineering lessons in the curriculum, increasing teacher salaries to attract the best technological minds to teaching, increasing the number of identifiable role models and mentors, and creating better incentives for schools to engage in outreach programs. Added to this list, based on the findings of this study, would be suggestions such as increasing or improving the career advisory services offered by schools, and establishing the relevance of content when teaching new concepts.

Undergraduate engineering students in Australia are required to undertake a period of practical work experience, typically 12 weeks, to graduate as an engineer. It has been argued that increasing student exposure to engineering practice in university may be beneficial to their understanding of transformative threshold concepts within the field, rather than simply emphasising engineering science within the classroom (Bennett and Male, 2016). This same principle may also be beneficial for senior secondary school students, not only for engineering but also for other careers. A number of students in this study referred to previous experiences they have had with engineering when stating what their personal role would be as an engineer. This is not to suggest that extended placements are suitable or necessary for senior secondary school students, but rather, exposing them to engineering in a variety of ways and settings, such as engineering projects, field trips, and guest speakers or outreach programs. Such exposure may help students develop a better understanding of the realities of the profession, allowing them to not only imagine but also experience their possible self, and make a more informed decision about whether or not to pursue it further.

6.7 Findings Compared to University Engineering Students

Stage theory suggests that there are differences in the rate of development through stages, and that there are often variations in the transition between these stages (Learner, 1976). This concept has been applied to a range of fields including engineering education, in which students' identification as engineers (by themselves and by others) and their disciplinary knowledge develops in stages throughout their education (Stevens et al. 2008). As a longitudinal study was not possible in the scope of this research, stage theory was used to study how perceptions of engineering develop throughout senior secondary school and university. This theory was applied to this study by comparing the similarities and differences in responses between senior secondary students and university engineering students to observe how their perceptions develop over time, or throughout stages of education. Given the limited sample of university engineering students, it is recognised that the following findings and comparisons are not conclusive and may be the result of bias in the data.

It was identified among senior secondary school students that having a close friend or relative who is an engineer resulted in students being more interested in pursuing engineering as a career. This influence was also evident among university students, with three-quarters of participants having a professional engineer as a close friend or relative. As outlined previously, this is likely due to students being allowed the opportunity to imagine themselves within the profession and realise their possible self.

Both senior secondary school students and university students were likely to reference problem solving, technical skills and creativity as characteristics of an engineer. However, while senior secondary school students also focused on technical characteristics such as maths/science ability, university students focused on socio-technical characteristics such as teamwork/interpersonal skills and communication. This difference in perception may be the result of a stronger emphasis placed on socio-technical skills at university through coursework or regular group projects, or possibly the result of practical work experience. While the idea that universities may emphasise technical skills over socio-technical skills as previously discussed may still apply, these findings suggest that university students become more aware of the importance of socio-technical skills in the latter stages of their education.

In considering how their own characteristics differed from those of an engineer, university students were less likely to say that there were no differences, indicating that students may become more self-aware as they develop a more comprehensive understanding of threshold concepts in engineering. While both groups considered technical knowledge to be a difference between themselves and engineers, university students were more likely to also identify creativity/innovation as a difference. Again, this may come as a result of their increased understanding of engineering, making them more aware of their strengths and weaknesses.

The greatest difference between senior secondary students and university students regarding the roles of engineers was project management. This may be partially due to the fact that several university participants in this study are doing a combined degree of engineering and project management, as well as an emphasis on group projects and practical work experience. Common themes among both groups were create/make, build/construct, and solve.

When imaging their possible selves, university students were more likely to include project management as one of their roles, as well as design and research. Senior secondary students focused their responses more on technical engineering work and calculations, perhaps due to the limited knowledge of the possible roles of engineers, or not having yet reflected upon how they imagine themselves in the future. University students were far more likely to be able imagine their personal role as an engineer, with only one student (4%) saying they were unsure compared to one-quarter of senior secondary school students who were unsure. This is consistent with Bennett and Male's (2016) analysis that students tend to select a field of study in which they can imagine themselves and which align to their projections of their future. Students who are not able to imagine themselves as an engineer will be less likely to pursue it, regardless of whether or not they have an interest in the field.

In considering the relevance of their learning to their development as an engineer, both groups identified that their courses would increase their technical skills and knowledge, however university students emphasised the development of 'engineering thinking.' This includes critical, analytical, and problem-solving skills. This was particularly prevalent among final year university students, who by this stage in their degree have perhaps come to realise the expansive and multi-faceted nature of engineering and the need for a particular way of thinking rather than a particular set of knowledge.

Finally, both groups held similar aspirations regarding their accomplishments as an engineer, hoping to work on significant problems or projects and having an impact on others and the world.

The main difference, once again, was that university students were less likely to be unsure of their response.

A comparison of senior secondary school and university students suggests that as students enter university and their understanding of engineering expands through exposure to more engineers and like-minded students, their perceptions of themselves and the profession shift. Students appear to become more capable of imagining their possible selves. This includes an understanding of the threshold concept of the role of engineers, how their current learning will contribute to their role, and what they will accomplish as an engineer. This is likely due to the increased exposure to the world of engineering, giving students more opportunities to reflect on how they might fit in. As students progress through university they also tend to identify more realistic components of engineering work such as the importance of teamwork and project management. This is likely a result of regular group work as well as practical work experience, and may imply that their understanding of threshold concepts, such as the role of engineers, is developing.

6.8 Limitations and Possible Improvements

The survey instrument has proven effective in obtaining the information required for this study and has allowed for the collection of useful and insightful data. As outlined in the methodology, some minor adjustments were made to the survey questions before distribution. Based on the survey responses, additional questions to the survey instrument may be added if the study was to be repeated. For example, asking students what interests (or disinterests) them about a career in engineering, which may provide a better insight into their motivations for pursuing (or not pursuing) the profession.

The length of the survey may also need to be reconsidered. Responses from 53 students (almost one-quarter of respondents) were not included in the analysis as they did not progress past the screening questions. It is assumed that upon moving to the page of the survey which contained the body questions, students were overwhelmed by, or unwilling to expend, the required effort to complete what may have seemed like a time-consuming exercise. This effect may be reduced by providing smaller text boxes for responses, which may appear less overwhelming and as though there is less work to do to answer the questions, or simply by removing some of the questions from the survey depending on the aim of the research.

Students also appeared to give more detailed responses in the first two questions of the survey, tapering off in the middle three, then providing more information when speaking of themselves and their future aspirations towards the end. The survey, if repeated, may benefit from adjusting the questions to feel more personal to the students which may give them an incentive to write in more detail. For example, rewording the first survey question to “In your opinion, what do you think are the characteristics of an engineer?”

As the survey was conducted online and without supervision, it was found while analysing the data that some students had directly copied and pasted information from the internet. For example, one student responded to the first question with a list that appears on Google when searching for ‘characteristics of an engineer.’ Students who are unsure of answers but do not want to appear that way, or students who fear giving the wrong answer, are likely to refer to other sources such as the internet or friends to help them. This was clear when responses were submitted at approximately the same time with similar answers. It was hoped that the likelihood of this happening would be reduced by assuring students that the survey was anonymous, as well as including a line at the commencement of the survey informing students that there are no right or wrong answers. While this cannot necessarily be avoided if anonymity is to be maintained, it is important to consider when referring to the findings of this and similar studies.

It was hoped that the number of survey responses obtained would be representative of the Year 11 and 12 population in New South Wales. For this reason, 90 schools throughout the state were contacted and invited to participate in the study. A number of schools responded saying that they were unable to take on any additional work at the moment due to an already heavy workload as a result of COVID-19. A number of schools also stated that the invitation to participate had come at a difficult time, with Year 12 Trial HSC and graduation approaching. This comment is relevant, and it was known that the timing of the survey distribution may result in fewer than anticipated responses. The survey was initially planned to be distributed approximately 2-3 weeks earlier, however due to delays in the ethics approval process, this was not possible. That aside, timing is an important factor to consider when planning research in schools and will be considered in all future research efforts.

In the initial research plan, it was proposed that students would be given the option to participate in an online interview with the researcher to discuss the survey questions in further detail. It was expected that students would not go into a great level of detail in the survey, and that this could be compensated for through a number of interviews. However, ethical requirements made it impractical to plan or perform these interviews due to the consent procedure required by schools and parents which would place an administrative burden on schools and be difficult to monitor. To avoid the risk of not meeting ethical requirements, or reducing the number of schools willing to participate by requiring them to perform additional administrative processes to manage consent, it was decided that only surveys would be used for the study.

Finally, some of the screening questions could not be utilised due to the number of responses obtained. For example, it was planned that a comparison would be made between types of schools (e.g. independent and public schools), however, the sample was not large enough to be representative of a particular type of school, and therefore comparison would be inaccurate.

7. Conclusion and Future Work

7.1 Conclusion

Geisinger and Raman (2013) identified six broad factors driving students to leave engineering at a tertiary level, all of which emerged either explicitly or implicitly in this research. This includes students' conceptual understanding, self-efficacy and self-confidence, secondary school preparation, interest and career goals, gender, and classroom climate (teaching and advising).

It was initially thought that this research would reveal a range of misperceptions based on students conceptual understanding, however, it was found that there is an obvious absence of any perception or understanding of engineering among many students, particularly in regards to the threshold concept of the role of engineers, even among those who are interested in a career in engineering. Many students, particularly females, appeared unconfident in their abilities to perform as an engineer, and could not imagine their possible selves within the profession. Many students were also unable to find any appropriate relevance to engineering in their study of mathematics or science, and of those who were able, there was a strong focus on technical knowledge and skills rather than a focus on developing the ability to problem solve and think analytically.

Fortunately, many of these trends seem to shift as students progress through the stages of tertiary engineering education. However, this does not negate the need for an increase in the quality and quantity of engineering education in schools to address the 'leaky pipeline' that exists in the profession. Secondary school students are not being given equal opportunities to develop an understanding of engineering, with many students' perceptions or interest stemming from their association with a professional engineer, rather than from their teachers, school curriculum, or programs. There is an obvious gap in students' education in which they are not being exposed to engineering to the extent that they are able to develop an understanding and make an informed decision on whether it is a field they may like to pursue beyond secondary school. As a result of this, universities and the Australian engineering industry are potentially losing out on capable and competent engineers.

The interest in this research expressed by participating schools indicates that educators are aware of the need for a shift in pedagogy and curriculum regarding engineering. However, teachers cannot be expected to be able to educate students in this field without additional training or assistance.

Schools and universities need to assist by increasing students' exposure to engineering, both theoretically and practically, so they can understand the role of engineers, how they might fit in, and have the opportunity to develop an interest based on a realistic representation of the profession.

7.2 Future Work

The findings of this study provide only an insight into the perceptions of engineering that exist among senior secondary school students in New South Wales and requires further work to be representative of the entire senior secondary school population. As with any research that explores trends within a population, this same study could be repeated among a larger population of students to gain an even deeper understanding or accurate representation. Similarly, the concept could be applied with some adjustments to include students in other year groups, perhaps even as young as primary school. The inclusion of interviews for students of all ages would be useful in obtaining more detailed responses from individual students, with a focus on determining how students develop their perceptions of engineering rather than simply focusing on what the perceptions are. By understanding where students' perceptions stem from, efforts can be focused on addressing the root cause of potential misperceptions or students' lack of perception.

It has been suggested in this report, as well as others, that teachers and other educators are able to implement changes to affect student perceptions and understanding of engineering. Surveys and/or interviews with teachers may provide valuable insights into their perception of engineering and their view on how inclusion of more engineering-focussed activities would be received by students in the classroom. Douglas et al. (2004) found that most teachers are "overwhelmingly positive" about engineering, that they believe that improving their understanding would make them a better teacher, and that their students would be interested in learning about engineering. However, they also believe that most of their students cannot succeed in engineering, particularly females and other minority groups. As teachers have the most frequent interaction with students, their insights and ideas would be highly valuable in developing approaches to address any concerns regarding perceptions of engineering among students and teachers.

Finally, major universities throughout Australia run outreach programs and educational initiatives targeted at senior secondary school students. These programs are designed to promote engineering as a profession, give students meaningful experiences and opportunities to meet young engineers, and gain an insight into what it is like to study engineering at university. By conducting this survey before and after students have been involved in one of these programs may be useful in measuring the effectiveness of the program, and the implications they have on students' perceptions and how they see themselves in engineering. This may be beneficial in tailoring future programs to address any potential concerns that arise.

7.3 Post-Analysis Reflexivity Statement

Having read extensively in preparation for and during and during the writing of this thesis, I found it challenging to not let the results of other studies influence my analysis. At times I felt as though I should look for certain patterns or themes based on the findings of previous research, and while this is necessary to a certain extent, I tried to remain mindful of what the data was actually showing and communicate that effectively to the reader.

I had initially thought that it sounded relatively simple to understand the general perceptions of engineering among students, and that conducting research among students would not be a significant challenge. However, I learnt that this is a far more complex and diverse topic than I anticipated; one which depends on multiple factors that need further research and consideration. This complexity came mainly through my learning of conceptual ecology, which has made me realise the contextual nature of learning and how this affects the perceptions of each individual.

I have found great satisfaction in this work, being consumed by it, and giving it my full attention for many weeks and months. My desire to work in secondary education has grown since the commencement of this study after having the opportunity to correspond with many schools throughout the State, and seeing just a small portion of the potential and knowledge that exists among secondary school students. I look forward to implementing what I have learnt from this research in the classroom as a STEM teacher, giving all students I contact the opportunity to learn about engineering, and to inspire and educate future engineers.

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10. Appendix

Appendix A. Comparison of Methodologies Outlined in Literature Review

Title & Author	**Objective**	**Scope**	**Findings**	**Strengths**	**Limitations**
Draw an Engineer Test (DAET): Development of a Tool to Investigate Students' Ideas about Engineers and Engineering (Knight & Cunningham, 2004)	To assess student's attitudes towards and perceptions of engineering before and after intervention and outreach activities.	384 students in grade 3-12 in Massachusetts were asked to write a response to "What does an engineer do?" and draw a picture of an engineer at work.	Responses included the terms 'builds' (30%) or 'fixes' (28%) followed by 'creates' (17%) or 'designs' (12%). Drawings included tools (23%), cars (19%) and computers (17%).	Large sample size covering a range of ages. Responses organised into themes and analysed according to gender and age.	No demographic data was collected except for age and gender. Students only given an opportunity to draw one perception they have of an engineer. Lack of drawing abilities may inhibit student's ability to communicate thoughts and ideas.
How Middle Schoolers Draw Engineers and Scientists (Fralick, Kearn, Thompson and Lyons, 2008)	To determine the perceived differences between engineers and scientists among school students.	1600 students in grade 3-8 in the United States were asked to draw an engineer and a scientist separately and write what they were doing in the picture.	Engineers were more often perceived as 'doers' while scientists were perceived as 'thinkers'. 29% of students did not draw anything for engineers,	Very large sample size covering a range of ages and demographics. Students given opportunity to compare two	Lack of drawing abilities may inhibit student's ability to communicate thoughts and ideas. Students not given opportunity to

Title & Author	Objective	Scope	Findings	Strengths	Limitations
			showing a lack of perception.	professions, provoking additional thought and consideration.	verbally communicate.
Sixth-Grade Students' Views of the Nature of Engineering and Images of Engineers (Karatas, Micklos and Bodner, 2010)	To determine how sixth-graders view the nature of engineering and differentiate between engineering and science	20 students in grade 6 in the United States were asked to draw an engineer at work and asked to talk about what engineers do. They were interviewed, being shown images of items of technology and asked about the role engineers might have had in the development of the item.	Students were most likely to view engineering as assembling vehicles, building structures, or fixing and repairing things.	Students were given the opportunity to verbally communicate their thoughts and ideas.	Very small sample taken from two similar schools.
What is an Engineer? Implications of Elementary School Student Conceptions for Engineering Education (Capobianco,	To determine how elementary school students perceive engineering, how these perceptions vary by grade, gender and community, and the implications of these	396 students from grade 1-5 in the United States were asked to draw an engineer at work and write what they are doing. 80 of the students were then interviewed and asked about their drawing in more detail.	Most students conceptualised an engineer as a mechanic or labourer who fixes, builds, or makes vehicles, engines, tools, and computers/electronics.	Students were given the opportunity to verbally communicate their thoughts and ideas.	Most students only given the opportunity to draw one engineer. Lack of drawing abilities may inhibit student's ability to communicate thoughts and ideas.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Diefes-dux, Mena and Weller, 2011)	perceptions on engineering education.		More than half of drawings depicted males.	Large sample size and a range of demographics.	
A Study of UK Secondary School Student's Perceptions of Science and Engineering (Bevins, Brodie and Brodie, 2005)	To determine how students perceive engineering and science at school and as a profession.	A survey with 19 questions was distributed among 542 students in 23 schools across England and 10 focus group interviews (150 students in total). The students were aged 12-14.	Most students did not have any perception of what an engineer or scientist does, and that the subjects were too hard in school. Students suggested that more career advice is needed, and professionals need to be brought into the classroom to encourage/inspire them.	Large sample size across a wide range of schools. Interviews conducted with some students allowing for verbal communication and further information on survey responses.	Survey uses quantitative measurements only so some student's do not have opportunity to express perceptions and understanding. Study focuses mainly on science, not engineering.
Developing an Engineering Identity in Early Childhood (Pantoya, Hunt and Aguirre-Munoz, 2015)	To promote STEM learning in Pre-K to Grade 2 using engineering-focused literacy practices and programs.	A book titled 'Engineering Elephants' is read to over 500 students in the United States. They are asked to draw what they would create if they were an engineer. Their responses are compared with	The students who read the book had heightened levels of creativity and a greater sense of what engineers do compared to children who did not read the book.	Very large sample size. Age-appropriate instrument for engaging young students.	Most students only given the opportunity to draw one engineer. Lack of drawing abilities may inhibit student's ability to communicate thoughts and ideas.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
		children who have not read the book.			
Examining the Impact of Mathematics Identity on the Choice of Engineering Careers for Male and Female Students (Cass, Hazari, Cribbs, Sadler and Sonnert, 2011).	To determine how mathematics identity (based on competence/performance beliefs, interest, and recognition (PCIR)) can lead to engineering as a career choice.	Over 10,000 high school students in the United States completed the FICS-Math survey questions, which included questions about PCIR beliefs about mathematics.	Mathematics interest and recognition are good predictors of engineering career choice. Performance/competency beliefs had a negative effect.	Very large sample size and range of demographics. Validated and tested survey tool.	Survey uses quantitative measurements only so student's do not have opportunity to express perceptions and understanding.
Perceptions of Engineering from Female Secondary College Students in Regional Victoria (Darby, Hall, Dowling and Kentish, 2003)	To determine the perceptions of females (ages 14-15 years) and assess the impact of these perceptions and the resultant limitations in career choice.	58 female students in Year 10 in Victoria, Australia were asked to draw a picture of an engineer in an appropriate environment, to name them, and describe their work. Focus groups interviews of 2-3 students were conducted in which they were asked about their perception of engineering	The perceptions and barriers that were identified included a lack of interest in the perceived image, a lack of knowledge of engineering, seeing engineering as a male-dominated industry, and limited recognisable role models.	Students were given the opportunity to verbally communicate their thoughts and ideas.	Limited only to year 10 students. Students in other year groups may exhibit different results. Focus group interviews mean ideas discussed by some students may not be their own, but rather are adopted from other students'

Title & Author	Objective	Scope	Findings	Strengths	Limitations
		as a profession and if they had considered it for themselves.			comments during the interview process.
Secondary Students Conceptual Understanding of Engineering as a Field (Montfort, Brown and Whritenour, 2013)	To determine how students perceive engineering in relation to the world around them (conceptual understanding) and develop ways to refine or mature their understanding.	27 students in the United States participated in 15 minutes interviews which asked questions about what they think of when they hear the word 'engineer', different types of engineering, and if they have considered engineering as a career for themselves.	Students who were interested in a career in engineering perceived it as hands-on activities such as fixing cars, bridges, or airplanes. Students who were not interested were able to identify a wider variety of types of engineering. Most students did not have a complex or rich perception of engineering.	Students were given the opportunity to verbally communicate their thoughts and ideas.	Interviews were conducted at a single low socioeconomic school. Interviews conducted in class around other students; potentially hindering responses given by students. Small sample size.
What preconceptions and attitudes about engineering are prevalent amongst upper secondary school pupils? An international study	To investigate upper secondary school students' attitude towards and their concept of engineering.	Conducted in 40 countries, including Australia, 7591 students were asked to respond to 33 Likert-type attitude items and 32 concept items. They were also asked to draw concept maps of engineering.	Students generally have a fairly good idea of what engineering is and a positive attitude towards it. The country in which the student lives and the subjects they study in school had a significant	Wide range of demographics recorded and used in analysis, including age, gender, class, parent's professions, experience with technology,	Small sample for a world-wide study. Results not conclusive for any individual country.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
(Kőycű and de Vries, 2015)			impact on their attitude towards engineering.	engineers among relatives, and presence of engineering curriculum at their school. Innovative approach by using concept maps rather than drawings.	
An Australian study of possible selves perceived by undergraduate engineering students (Bennett and Male, 2016)	To use presage thinking to understand what students want to achieve as engineers, what are their perceptions of engineering practice, and what fears they hold about their ability to achieve their career aspirations.	49 undergraduate engineering students at a university in Perth were given a survey that included questions regarding their understanding on what an engineer looks like and does, and how they view their personal role as an engineer in the future.	Many students have a poor understanding of the realities of engineering work and viewed themselves as less creative than other engineers. Most students focused on the technical nature of engineering, such as design and project management.	Extended response answers allowed students to evaluate on their responses and have time to gather their thoughts before recording them.	Small sample size. Possibility of responses being misunderstood by researcher or not being read as the student intended. Does not explore how these perceptions change over time.
Why Do Students Choose Engineering? A	To determine how engineering students' engineering-related value	11 students (5 male and 6 female) at a technical university in the United	Students with low attainment values (i.e. does not align with sense	Longitudinal study showing how students'	Small sample size with lack of

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Qualitative, Longitudinal Investigation of Students' Motivational Values (Matusovich, Streveler and Miller, 2010)	beliefs contribute to their choices to engage and persist in earning an engineering degree.	States were individually interviewed each year for the 4 years of their degree. They were asked why they chose engineering, how they differ from other engineering students, and what they imagine their role to be when they graduate.	of self) are more likely to leave engineering. This may be due to a lack of understanding of what engineering is when choosing to study it.	beliefs and ideas change throughout the course of their degree. Individual interviews give the students a chance to communicate their beliefs and ideas.	diversity in participants. Lack of anonymity due to interviews may result in student's unwillingness to share thoughts honestly.
On the Development of Professional Identity: Engineering Persisters Vs Engineering Switchers (Pierrakos et al., 2009)	To develop a greater understanding of student's engineering identities and what contributes to the development of these identities throughout the undergraduate experience.	Focus groups and interviews were conducted in the United States with 4 first-year engineering students and 4 students who switched out of engineering in first year. The interviews focussed on the reasons and influences for selecting the engineering major, knowledge and perceptions of	Engineering persisters (end of first year) tend to have had more exposure and a more accurate understanding of engineering as a profession, often due to a relative or friend who is an engineer. Despite this exposure, when their knowledge of engineering as a profession was compared with engineering	Comparison between two groups of students (persisters and switchers). Individual interviews give the students a chance to communicate their beliefs and ideas.	Small sample size. Lack of anonymity due to interviews may result in student's unwillingness to share thoughts honestly.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
		engineering, and the students' sense of belonging and identifying with the engineering major and profession.	switchers there was little difference.		
The Dynamic Image of the Engineer (Pritchard and Mina, 2013)	To determine what students think it means to be an engineer.	136 engineering students in the United States were asked to respond to the question - Imagine that you are at a party, and a person with no particular background in engineering asks you, "What is engineering, and what does it mean to be an engineer?"	The most common responses included themes of technical problem solving, design and innovation. Less likely responses included ethical behaviour, advancing society, leadership, and communication.	Responses were tabulated against predetermined criteria to maintain accuracy and consistency in analysis.	Lack of diversity in sample with all students from the same university. Question may be understood differently by participants.
First Year Engineering Students Perceptions of Engineers and Engineering Work (Bennett, Kapoor,	To understand first-year engineering students' perception of their competencies, identity, self-efficacy, motivation, and career.	260 first-year engineering students from a large urban Australian university were asked to list 3 characteristics of an engineer and this was	Most responses related to 'Professionalism and Personal Attributes' rather than 'Knowledge and Skill Base' and 'Engineering Application Ability'. This may show	Use of predetermined standards from a professional body to compare responses against.	Potential for researcher error when determining which Competency Guideline the student's response best fits into.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Kaur and Maynard, 2015)		compared with Engineers Australia Competency Guidelines. They were also asked to list perceived differences between themselves and an engineer.	that students enter university without a clear idea of their future career-selves.	Diverse cohort of students, with 49% of participants being international students. Large sample size.	
Student's Perceptions of the Engineering Field and Implications for Interest in the Field (Towers, Simonovich and Zastavker, 2011)	To determine students' perceptions of the skills required by the engineering profession and how they compare with the Accreditation Board of Engineering and Technology (ABET) Engineering Criteria 2000.	12 first-year engineering students in the United States were individually interviewed about their Physics and Engineering Design courses and if these subjects are perceived as useful for their future engineering careers.	Students narratives only touched on 6 out of the 11 ABET Engineering Criteria, showing they only have a partial understanding of the realities of engineering work.	Use of predetermined standards from a professional body to compare responses against. Individual interviews give the students a chance to communicate their beliefs and ideas.	Small sample size with lack of diversity. Potential for researcher error when determining which Engineering Criteria the student's response best fits into.
Students Changing Images of Engineering and Engineers	To determine how the perception of engineering as a profession develops	Interview conducted at 4 different universities with 16 students over 4 years to see how their	Students perception of engineering work started out hopeful and gradually became more	Longitudinal study showing	Small sample, however diversity is included between

Title & Author	Objective	Scope	Findings	Strengths	Limitations
(Jocuns, Stevens, Garrison and Amos, 2008)	over the course of a 4-year engineering degree.	perception of engineering changed over the course of their studies. Questions were related to the role of engineers, what it takes to be a good engineer, and how the student feels they compare to other students.	mundane throughout their degree. Students in first-year typically had very little understanding of what they would be doing as engineers.	how perceptions change over time. Individual interviews give the students a chance to communicate their beliefs and ideas.	the different universities.
Student Perceptions of Engineering Entrepreneurship: An Exploratory Study (Dabbagh and Menascé, 2006)	To determine how strongly attrition rates are related to students' perceptions of the engineering profession, and what engineering programs can do to better portray the profession and motivate students to pursue a career in engineering.	20 first-year engineering students in the United States were given the challenge of designing an online travel agent system (entrepreneurial task), while the remainder of the class did the traditional task of building a land sailor. A Likert-type survey used to identify perceptions of engineering was then given to the students in both groups.	The entrepreneurial task did not cause any change in the perception of the technical aspect of engineering work, but had a significant impact on the perception of professional skills, including leadership skills, effective communication, creative thinking, patience, asking for help, assessing their own competency, and defining learning goals to increase competency.	Innovative approach showing the impact of different pedagogy. Likert-type survey used to maintain consistency between the two groups.	Student's may not be able to fully communicate their perception of engineering using a Likert-type survey.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Influences on the Development of Students' Professional Identity as an Engineer (Dehing, Jochems and Baartman, 2013)	To obtain an understanding of how an engineering student develops their professional identity as an engineering.	Interviews with 6 recent engineering graduates and 4 of their line supervisors in Australia were recorded and coded using Gee's four types of identity (nature-identity, institution-identity, discourse-identity and affinity-identity).	Most significant factors contributing to engineering identity develop include industry experience during university, the support the student receives from their cohort, and the large contextual projects conducted in their coursework.	Engages supervisors of recent graduates to provide an external perspective of the graduates engineering identity.	Small sample size and lack of diversity.
Factors Relating to Engineering Identity (Meyers et al., 2012)	To determine the stage in which engineering students consider themselves an engineer.	1097 engineering students in the United States did an online survey that asked if they consider themselves to be an engineer, followed by a table of survey items that required students to indicate if they felt that item is necessary to be considered an engineer.	Most students considered themselves to be an engineer, particularly those in the later years of their coursework. The items most cited by students necessary to be an engineer were 'making competent design decisions' and 'working with others by sharing ideas.'	Large sample size with a range of demographics that have been recorded and considered. Online survey resulting in anonymity, potentially leading to more honest responses.	The study was only conducted at one university. The study only considers students who persisted in engineering, and those who are full-time students.
A Combined Model for Predicting	To draw on prior studies on how engineering identity is influenced by	1202 undergraduate engineering students at two universities in the	Engineering beliefs are equally as important as maths and physics	Large sample size.	Does not consider the background of students e.g.

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Engineering Identity in Undergraduate Students (Patrick, Borrego and Seepersad, 2018)	performance/competence, interest and recognition in maths and physics, and determine the impact of engineering factors on engineering identity.	United States were surveyed regarding their performance/competence, interest, and recognition in engineering, followed by questions regarding how/if they identify as an engineer.	beliefs in influencing the engineering identity of students. Interest is the most significant contributor to engineering identity.	Innovative approach of using an engineering identity scale based on prior research to measure engineering identity in students.	influence of mentors, school attended.
Gender Differences in Freshman Engineering Students' Identification with Engineering (Pierrakos et al., 2010)	To determine why students enter and persist in engineering at university.	Online survey distributed to 45 first-year engineering students in the United States asking about their exposure to engineering, what appeals to them about engineering, and why they want to be an engineer.	Most common exposure to engineering was STEM courses. Most common appeal to engineering was the hands-on nature of the work. Most common reason for wanting to be an engineer was an interest in building/designing and having a societal impact.	Open-ended survey questions conducted online allows for opportunity for students to give thoughtful extended answers.	Only considers first-year students. Small sample size.
Engineering Identity Development Among Pre-	To examine the development of the Engineering Identity Development Scale	A survey of 20 questions addressing 4 elements of engineering identity (academic identity,	The factors that have the strongest influence on engineering identity are	Innovative approach used by developing and	Sample size is not representative. EIDS is more effective when conducted in a

Title & Author	Objective	Scope	Findings	Strengths	Limitations
Adolescent Learners (Capobianco, French and Diefes-Dux, 2012)	(EIDS) and determine which factors are most influential in engineering identity development of pre-adolescent students.	school identity, occupational identity, engineering aspirations) was developed and administered to 214 grade 1-5 students in the United States.	academic identity and engineering aspirations.	administering EIDS.	longitudinal study. Adult-like survey was given to children, creating potential complications in understanding.
Do Engineers Beget Engineers? Exploring Connections Between the Engineering-related Career Choices of Students and their Families (Godwin, Potvin and Hazari, 2014)	To determine the connections between family background and students' educational aims and outcomes in engineering.	Data was compiled from a large national survey in the United States of 6772 first-year general English course (including engineering and non-engineering students) and 17 interviews with high school students. Information from the data included interest in engineering/science as a future career and the influence/career of a family members.	Siblings or extended family members have a stronger influence than parents on students choosing to study engineering. Fathers tend to have a stronger influence than mothers on engineering as a career choice, especially when a good relationship exists between the parent and student.	Very large sample size from around the United States for quantitative data. Use of qualitative and quantitative data.	Small sample size for interviews and lack of diversity compared to quantitative data.

Appendix B. Definition of Themes

B1. Q1 What are the characteristics of a ________ engineer?

Emergent Theme	**Description**
Problem Solving	References to enjoying or having an aptitude for solving problems
Technical Knowledge / Skills	References to technical knowledge or tasks relating to engineering, or skills required to complete such tasks
Maths / Science Ability	References to enjoying or having an aptitude for mathematics and/or science
Creative / Innovative	References to creativity or innovation
Smart / Intelligent	References to a being smart or intelligent
Critical / Analytical	References to critical and analytic thinking
Communication Skills	References to written and/or oral communication
Teamwork	References to working in a team or with others
Adaptable / Quick-thinker	References to the ability to adapt to situations quickly or problems quickly
Hardworking / Dedicated	References to commitment, dedication, and hard work
Patient / Persistent / Resilient	References to patience, persistence, or resilience
Attention to Detail / Meticulous	References to being meticulous or having an attention for detail
Organised / Time Management	References to being organised or managing time well
Practical	References to being practical, working with hands, or implementing theory into real life
Desire to Improve Society / World	References to having a desire to help people or improve society or the world
Logical	References to logical thinking
Interpersonal Skills	References to being social, empathetic, or likeable
Leadership	References to leadership or leading a team
Unsure	Was not able to the answer question

B2. Q2 What differences are there (if any) between the above characteristics and you as a person?

Emergent Theme	Description
Problem Solving	References to enjoying or having an aptitude for solving problems
Technical Knowledge / Skills	References to technical knowledge or tasks relating to engineering, or skills required to complete such tasks
Maths / Science Ability	References to enjoying or having an aptitude for mathematics and/or science
Creative / Innovative	References to creativity or innovation
Smart / Intelligent	References to a being smart or intelligent
Critical / Analytical	References to critical and analytic thinking
Communication Skills	References to written and/or oral communication
Teamwork	References to working in a team or with others
Adaptable / Quick-thinker	References to the ability to adapt to situations quickly or problems quickly
Hardworking / Dedicated	References to commitment, dedication, and hard work
Patient / Persistent / Resilient	References to patience, persistence, or resilience
Attention to Detail / Meticulous	References to being meticulous or having an attention for detail
Organised / Time Management	References to being organised or managing time well
Practical	References to being practical, working with hands, or implementing theory into real life
Desire to Improve Society / World	References to having a desire to help people or improve society or the world
Logical	References to logical thinking
Interpersonal Skills	References to being social, empathetic, or likeable
Leadership	References to leadership or leading a team
Unsure	Was not able to the answer question
None	References to their being no difference between self and an engineer

B3. Q3 What do you see as the roles of an engineer?

Emergent Theme	Description
Create / Make	References to creating or making something new
Design	References to design
Improve / Advance / Develop	References to improving, advancing, or developing a product, process, or condition
Solve	References to solving problems
Build / Construct	References to building or constructing products or structures
Using Technology / Computer	References to working with technology or computers, either as a tool or as an output of an engineering process
Help People / Society / World	References to helping people, society or the world
Work with Machines / Engines	References to working with machines or engines, either as a tool or as an output of an engineering process
Research / Study / Analyse	References to researching, studying or analysing a problem, phenomenon or behaviour
Apply Maths / Science	References to the application of mathematics and science to the real world
Fix / Repair	References to fixing or repairing something
Maintain / Monitor	References to maintaining or monitoring the condition of something
Innovate	References to innovation
Invent	References to inventing something
Ensure Safety	References to ensuring the safety of a new or existing item, device, or structure
Test / Trial / Experiment	References to testing or trialling a new or existing item, device, or structure
Project Management	References to planning work or projects, or making decisions
Calculate	References to conducting calculations
Unsure	Was not able to answer the question

B4. Q4 What do you imagine your personal role to be?

Emergent Theme	**Description**
Technical Engineering Work	References to technical components or tasks relating to engineering
Improve the World / Society	References to improving the world, society, standard of living, or processes
Teamwork	References to working in a team or working with others
New ideas / Innovate	References to thinking of new ideas or innovation
Design	References to designing machines, equipment, engines or structures
Research	References to conducting research
Leadership	References to leadership roles among a team of engineers
Build / Construct	References to building or constructing products or structures
Non-engineering roles	References to any roles that are not related to engineering
Project Management	References to managing projects, planning, or making decisions
Inspecting / Testing	References to inspecting or testing new or existing products or structures
Unsure	Was not able to answer the question

B5. Q5 How will the learning in ________ contribute to your development as an engineer?

Emergent Theme	**Description**
Technical Skills / Calculations	References to the development of technical or analytical skills, or calculations required in engineering
Knowledge of the Field	References to knowledge of a particular field of engineering or concepts involved in engineering
Engineering Thinking	References to problem solving, critical and analytical thinking, or thinking logically
Help with Future Studies	References to current learning making the transition to tertiary engineering studies easier
Knowledge of the World	References to current learning giving general knowledge of the world and how things work
Teamwork	References to practice working in teams
Don't want to be an engineer / It won't	References to not wanting to be an engineer so current learning will not be useful
Unsure	Was not able to answer the question

B6. Q6(a) Imagine yourself in 10 years' time. What will you be doing?

Emergent Theme	Description
Non-engineering related work	References to working in a career not related to engineering
Engineering related work	References to working as an engineer
General Work	References to working in general with no further details given
Helping Others	References to helping others
Studying	References to being at university or undertaking training
Enjoyable Work	References to enjoying a job
Steady / High Income	References to having a steady or high income
Non-work related	References to non-work-related activities such as travel, family, or hobbies
Impact on the World	References to having an impact on a global scale
Unsure	Was not able to answer the question

B7. Q6(b) In a sentence, describe what you dream you will have achieved as an engineer over this time.

Emergent Theme	**Description**
Significant Projects / Problems Solved	References to working on large or important projects or solving problems
Impact on Others	References to having made an impact on an individual or personal scale
Career Satisfaction	References to having enjoyed work or feeling satisfied with achievements
Impact on the World	References to having made an impact on a global scale
Steady/High income	References to earning a steady or high income
Career Progression	References to progressing in career
Graduated from University	References to having graduated or finished University
Travelled for Work	References to travelling the world for work purposes
Unsure	Was not able to answer the question

Appendix C. Full Thematic Analysis of Survey Responses

C1. Q1 What are the characteristics of a ________ engineer?

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**F**	**%**	**No.**	**No.**	**%**
Technical Knowledge / Skills	26	41%	27	29%	0	53	34%
Problem Solving	22	35%	28	30%	0	50	32%
Maths / Science Ability	11	17%	27	29%	0	38	24%
Creative / Innovative	13	21%	21	23%	0	34	22%
Smart / Intelligent	9	14%	17	18%	0	26	17%
Unsure	9	14%	15	16%	0	24	15%
Critical / Analytical	9	14%	13	14%	0	22	14%
Communication Skills	9	14%	13	14%	0	22	14%
Teamwork	6	10%	10	11%	0	16	10%
Practical	6	10%	9	10%	0	15	10%
Adaptable/Quick-thinker	5	8%	9	10%	0	14	9%
Desire to Improve Society / World	4	6%	9	10%	0	13	8%
Patient / Persistent / Resilient	5	8%	8	9%	0	13	8%
Hardworking / Dedicated	4	6%	8	9%	0	12	8%
Attention to Detail / Meticulous	3	5%	8	9%	0	11	7%
Organised / Time Management	5	8%	3	3%	0	8	5%
Logical	3	5%	5	5%	0	8	5%
Interpersonal Skills	3	5%	4	4%	0	7	4%
Leadership	2	3%	2	2%	1	5	3%

C2. Q2 What differences are there (if any) between the above characteristics and you as a person?

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
None	23	37%	19	20%	0	42	27%
Unsure	15	24%	21	23%	0	36	23%
Technical Knowledge / Skills	7	11%	9	10%	0	16	10%
Maths / Science Ability	3	5%	10	11%	0	13	8%
Creative / Innovative	3	5%	9	10%	0	12	8%
Not interested / passionate	2	3%	10	11%	0	12	8%
Problem Solving	2	3%	7	8%	0	9	6%
Communication Skills	2	3%	7	8%	0	9	6%
Smart / Intelligent	1	2%	7	8%	0	8	5%
Critical / Analytical	1	2%	3	3%	0	4	3%
Patient / Persistent / Resilient	0	0%	4	4%	0	4	3%
Attention to Detail / Meticulous	1	2%	3	3%	0	4	3%
Organised / Time Management	3	5%	1	1%	0	4	3%
Adaptable / Quick-thinker	1	2%	2	2%	0	3	2%
Practical	0	0%	3	3%	0	3	2%
Interpersonal Skills	0	0%	1	1%	1	2	1%
Teamwork	1	2%	0	0%	0	1	1%
Hardworking / Dedicated	0	0%	1	1%	0	1	1%
Logical	0	0%	1	1%	0	1	1%
Desire to improve the world	0	0%	0	0%	0	0	0%
Leadership	0	0%	0	0%	0	0	0%

C3. Q3 What do you see as the roles of an engineer?

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Create / Make	10	16%	31	33%	1	42	27%
Design	14	22%	20	22%	0	34	22%
Improve / Advance / Develop	12	19%	21	23%	1	34	22%
Build / Construct	9	14%	24	26%	0	33	21%
Solve	18	29%	12	13%	0	30	19%
Help People / Society / World	8	13%	19	20%	0	27	17%
Unsure	14	22%	12	13%	0	26	17%
Using Technology / Computer	11	17%	12	13%	0	23	15%
Innovate	5	8%	10	11%	0	15	10%
Apply Maths / Science	6	10%	8	9%	0	14	9%
Work with Machines / Engines	4	6%	10	11%	0	14	9%
Research / Study / Analyse	4	6%	10	11%	0	14	9%
Fix / Repair	3	5%	9	10%	1	13	8%
Maintain / Monitor	6	10%	5	5%	0	11	7%
Project Management	5	8%	5	5%	0	10	6%
Invent	3	5%	6	6%	0	9	6%
Ensure Safety	2	3%	6	6%	0	8	5%
Test / Trial / Experiment	1	2%	5	5%	0	6	4%
Calculate	1	2%	0	0%	0	1	1%

C4. Q4 What do you imagine your personal role to be?

	Male (n=35)		Female (n=19)		Unk (n=1)	Total (n=55)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Unsure	7	20%	6	32%	0	13	24%
Technical Engineering Work	10	29%	2	11%	0	12	22%
Improve the World / Society	8	23%	2	11%	0	10	18%
New Ideas / Innovate	6	17%	2	11%	0	8	15%
Teamwork	4	11%	2	11%	1	7	13%
Design	3	9%	3	16%	0	6	11%
Research	2	6%	2	11%	0	4	7%
Leadership	0	0%	3	16%	0	3	5%
Build / Construct	1	3%	2	11%	0	3	5%
Non-engineering roles	2	6%	1	5%	0	3	5%
Project Management	2	6%	1	5%	0	3	5%
Inspecting / Testing	2	6%	1	5%	0	3	5%

C5. Q5 How will the learning in ________ contribute to your development as an engineer?

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Technical Skills / Calculations	18	29%	34	37%	1	53	34%
Knowledge of the Field	27	43%	22	24%	0	49	31%
Unsure	10	16%	22	24%	0	32	20%
Engineering Thinking	12	19%	12	13%	0	24	15%
Don't want to be an engineer / It won't	6	10%	10	11%	0	16	10%
Help with Future Studies	2	3%	9	10%	0	11	7%
Knowledge of the World	4	6%	4	4%	0	8	5%
Teamwork	0	0%	1	1%	0	1	1%

C6. Q6(a) Imagine yourself in 10 years' time. What will you be doing?

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Non-engineering related work	27	43%	55	59%	0	82	52%
Engineering related work	15	24%	8	9%	1	24	15%
Unsure	12	19%	11	12%	0	23	15%
Non-work related	6	10%	17	18%	0	23	15%
General Work	7	11%	11	12%	0	18	11%
Helping Others	2	3%	5	5%	0	7	4%
Studying	2	3%	5	5%	0	7	4%
Impact on the World	1	2%	6	6%	0	7	4%
Enjoyable Work	3	5%	3	3%	0	6	4%
Steady / High Income	2	3%	4	4%	0	6	4%

C7. Q6(b) In a sentence, describe what you dream you will have achieved as an engineer over this time.

	Male (n=63)		Female (n=93)		Unk (n=1)	Total (n=157)	
Emergent Theme	**No.**	**%**	**No.**	**%**	**No.**	**No.**	**%**
Significant Projects / Problems Solved	16	46%	10	53%	0	26	47%
Unsure	7	20%	7	37%	0	14	25%
Impact on the World	6	17%	3	16%	0	9	16%
Impact on Others	2	6%	4	21%	0	6	11%
Career Satisfaction	4	11%	1	5%	1	6	11%
Steady/High Income	3	9%	1	5%	0	4	7%
Career Progression	2	6%	1	5%	0	3	5%
Graduated from University	1	3%	0	0%	0	1	2%
Travelled for Work	1	3%	0	0%	0	1	2%