

Zen and the Art of Engineering Education

EEA Conference 2014, 18 - 20 June, Auckland

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Acknowledgement - The authors would like to thank David Wilson (New Zealand Qualifications Authority), Gurusingham Sathiyandra (Ministry of Education), Geoff Knight, Carl Johnston and Pip Collins (Burnside High School), Nathan Mehrtens (Christchurch Boys High School), Tim McCall (Cashmere High School), Brent Cummack (St Andrew's College) and ENGR101 students for their input.

ABSTRACT

Attracting the next generation to consider the electricity industry as their career choice is something that has long been discussed. The 'Smart People for a Sustainable Future' session at the 2013 EEA conference brought this topic into view and highlighted the scale of industry concern. Anecdotal evidence suggests that there is a noticeable void of young engineers in the industry to acquire knowledge from experienced senior professionals and smoothly transition into senior roles.

The title of this paper is a play on the book title "Zen and the Art of Motorcycle Maintenance" by Robert M. Pirsig [1]. It parallels the concept of 'flight from science' coined by the Japanese with the two approaches to life, and indeed understanding and maintenance of their motor cycles, by the narrator's friend and the narrator. The Japanese have observed an increasing use of technology by younger generations coupled with an increasing reluctance to 'lift the bonnet' and understand how the technology actually works. Is the world moving to the 'romantic' philosophical approach of the narrator's friend, where he relies on his expensive motorcycle to run smoothly and entrusts it to expensive professionals to maintain? And therefore is the world turning its back on the 'classical' philosophy of the narrator, of diagnosing and repairing problems oneself? Or is it simply too difficult to maintain a modern machine?

Having posed this question the paper analyses enrolment trends in Mathematics and Physics at high-school level, and looks for trends that might shed some light on these questions. Using this information the paper attempts to answer the question of serious concern to the industry: what is an indication of future New Zealand engineering graduate numbers. Preliminary findings from EPECentre focus groups with high-school teachers is also summarised to give the perspective of teachers in the 'system'.

1 INTRODUCTION

In an asset intensive electricity industry, some might argue that the greatest asset is the people who work in the industry. Many of those people received their training at universities and polytechnics around New Zealand. At some point in their schooling prior to university, they made a decision on their choice of tertiary education. Moreover, right now thousands of New Zealand secondary school students are forming ideas of careers, and therefore tertiary education, to pursue.

Research / surveys conducted by the EPECentre in 2013 shows that the majority (approximately 62%) of students enrolled in Electrical and Electronic Engineering (EEE) degrees make their minds up to study engineering, and EEE, while at secondary school. This led the EPECentre to look more closely at the secondary school education system. The purpose of this was to understand some of the factors influencing secondary students, and challenges faced by teachers, and thereby target outreach, scholarship, and educational programmes more effectively. This paper summarises the NCEA education system, introduced in 2002, and which is still new to many people. It specifically looks at the Year 13 engineering prerequisite subjects (Calculus and Physics), and delves further into these to look at interest in the electrical aspect of Physics – an early indicator of interest in the EEE degree. The paper then looks at completion rates of tertiary degrees, certificates, and diplomas, to look for trends and try to identify relationships with the introduction of NCEA. Findings are presented from focus groups with secondary school Physics teachers, conducted by the EPECentre, which explain some of the trends seen in Year 13 Physics.

Finally results of a survey of first (Intermediate) year engineering students are presented and discussed to confirm how those students ended up at university studying towards engineering degrees, and a discussion of the problem of reducing EEE graduate numbers in a global context is discussed.

The paper concludes that there is a trend towards less students opting for the electrical systems part of the Year 13 Physics paper because it is seen as difficult, and that teachers are in need of up-to-date resources and training programmes to teach the electrical systems courses, and in turn inspire students to undertake EEE degrees. However it is also concluded that it is careers that influence students more than teachers, and therefore showing a clear career pathway in Engineering, and EEE, at the high school level, is important. New Zealand is not alone in this, with other countries finding it a problem also.

2 NATIONAL CERTIFICATES OF EDUCATIONAL ACHIEVEMENT (NCEA)

Since its introduction in 2002, the NCEA qualification system has progressively changed the secondary qualification system from the previous ‘School Certificate’, ‘Sixth Form Certificate’ and ‘University Entrance’ (UE), Bursaries and Scholarships’ system [2]. NCEA shows credits

and grades for separate skills and knowledge by enabling students to gain credits from both traditional school curriculum areas and alternative programmes. While not designed specifically for above average and high-achieving abilities, NCEA is used as the benchmark for selection by universities and polytechnics.

NCEA requires students to complete a minimum number of 80 credits at each of the three levels, where each credit is an approximate ten hours of learning time. Generally, secondary school systems operate in such a way that Level 1 is completed during Year 11, Level 2 in Year 12 and Level 3 in Year 13 (the final year of high-school). Students choose to study subjects of their choice that will normally consist of a number of internal and external assessments that make up credits. Universities require students to have completed Level 3, 10 literacy credits at Level 2 or above, 10 numeracy credits at Level 1 or above and three subjects at Level 3, made up of 14 credits each, in three approved subjects [3].

2.1 NCEA ASSESSMENT GRADES AND ENDORSEMENT

There are two types of standards that schools assess: The Unit Standard (US) and the Achievement Standard (AS). USs usually assess vocational based skill and lead to specific trade and apprenticeships related qualifications. There are just two grades ‘Achieved (A)’ for meeting the criteria of the standard and ‘Not achieved (N)’ if a student does not meet the criteria of the standard. There are no US based assessments for Physics at Level 3. ASs can be assessed by internal assessments in school and by external assessments which are assessed by NZQA at the end of the year. There are four grades. ‘Achieved (A)’ for a satisfactory performance, ‘Merit (M)’ for very good performance, ‘Excellence (E)’ for outstanding performance and ‘Not achieved (N)’ if students do not meet the criteria of the standard.

To recognise higher achievement, the NCEA qualification offers endorsements with Merit or Excellence. There are two types of Endorsements, a student *Certificate Endorsements* where students achieve 50 or more credit at Excellence or Merit level, and *Course Endorsements* where a student gains 14 or more credits at Excellence or Merit level in a single year. To achieve Course Endorsements, a student must gain 14 or more credits where at least three credits must come from external, and three from internal assessments. The remaining eight credits can come from either external or internal assessments [4].

2.2 NCEA LEVEL 3 PHYSICS AND ELECTRICITY

Subject areas in NCEA Level 3, including Physics, are optional. This includes electricity ASs. A list of the level 3 ASs for physics are presented in Table I. Generally, secondary schools will offer one or two internal assessments (up to 7 credits) at Level 3 and teach content in support of all three external assessments (up to 16 credits). During external examinations, students are able to choose not to participate in ASs of the external assessments they deem too difficult, yet still retain endorsements as long as they meet the overall criteria. For example, with reference to

Table I, a student may select to participate in mechanical systems (6 credits) and wave systems (4 credits) in the external examination, and one internal assessment that offers 4 credits to make up the 14 credit requirement. The key point is that any student has a choice of which AS to study for and attempt in the final exam. The choice is such that they may completely exclude certain ASs. For example, a student may make a deliberate choice to exclude the ‘electrical systems’ AS if they feel it is likely to yield poor results, perhaps because they find it more difficult.

TABLE I ACHIEVEMENT STANDARDS RELATED TO NCEA LEVEL 3 PHYSICS

Achievement Standard Reference	Achievement Standard Name	Credits	External Internal	or	Subject Reference
91521	Carry out a practical investigation to test a physics theory relating two variables in a non-linear relationship	4	Internal		3.1
91522	Demonstrate understanding of the application of physics to a selected context	3	Internal		3.2
91523	Demonstrate understanding of wave systems	4	External		3.3
91524	Demonstrate understanding of mechanical systems	6	External		3.4
91525	Demonstrate understanding of Modern Physics	3	Internal		3.5
91526	Demonstrate understanding of electrical systems	6	External		3.6
91527	Use physics knowledge to develop an informed response to a socio-scientific issue	3	Internal		3.7

We are interested in the number of students opting to take Physics in Year 13. Moreover, we are particularly interested in the number of students who opt for the ‘electrical systems’ AS (Subject Reference 3.6 from Table I) in Year 13. The following sections investigate this.

3 YEAR 13 CALCULUS AND PHYSICS

In order to understand enrolment numbers in secondary school Mathematics and Physics, ‘*Secondary schools enrolment data for the past ten years by subject*’ and ‘*NCEA Physics Results for Levels 1 to 3*’ were requested and obtained from the Ministry of Education (MoE) and the New Zealand Qualifications Authority (NZQA) respectively. The data was used to obtain absolute Year 13 Calculus and Physics enrolment numbers and trends. It was also used to identify NCEA 3.6 (electricity) examination results, and compare them against other external examination results.

3.1 CALCULUS AND PHYSICS ENROLMENT TREND

Figure 1 presents Year 13 enrolment trends in secondary Physics and Calculus at a national level. The decline in enrolment between 2003 and 2005 coincides with the introduction of NCEA Level 3 replacing Bursaries in 2004. Based on discussions in sections to follow, it is the authors' speculative assertion that the decline may have been related to Physics and Calculus being perceived as the more difficult subject by students who wished to limit their risk of 'Not Achieving' Level 3 credits at a time when NCEA was first introduced.

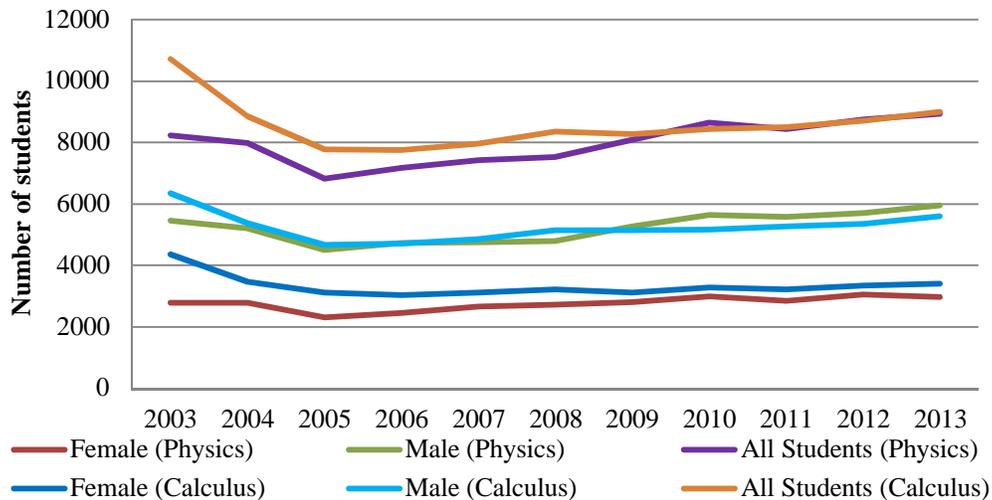


FIGURE 1: YEAR 13 PHYSICS AND CALCULUS, NUMBER OF STUDENTS ENROLLED IN COURSE.

Overall, Year 13 enrolment numbers in Calculus and particularly Physics is rising which is likely to lead on to a greater number of tertiary level engineering students. However, the following sections present findings and discusses why rising enrolment numbers in Year 13 Physics may not necessarily lead on to a rising trend of students pursuing EEE degrees.

3.2 NCEA PHYSICS AND ELECTRICITY ACHIEVEMENT STANDARDS

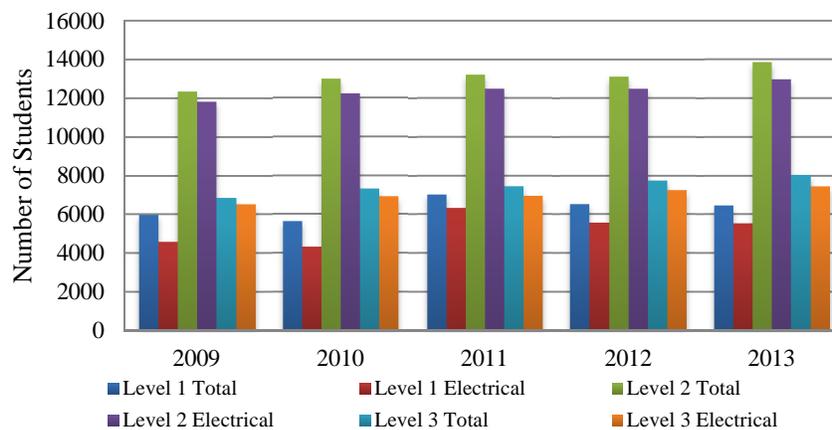


FIGURE 2: NCEA PHYSICS - NUMBER OF STUDENTS ENROLLED IN EXTERNAL AS

Figure 2 shows a comparison between the number of students sitting the External Achievement Standards (Ex ASs) in NCEA Physics from 2009 until 2013 for each level and the number taking the electrical based Ex AS. This data gives an indication of how many schools are teaching the electrical component of NCEA Physics. There are a number of conclusions that can be drawn from this data.

- There is an overall trend of growth in student numbers for each level of Physics which is consistent with Figure 1.
- There is a reasonably significant drop in student numbers between Level 2 and Level 3 suggesting failure and/or discontinuing of Physics for some students. However, the number appears to be constant and combined with the growth in overall student numbers represents a decreasing percentage of students' taking Level 3 Physics attrition.
- The electrical Ex AS appears to be widely taught with nearly all students taking Physics also taking the electrical component, especially in Level 3.

This is largely encouraging news for the electricity industry. More students taking physics and calculus are likely to translate into more graduates in key degrees for the electrical industry. Unfortunately, if one digs a little deeper some troubling trends begin to emerge. Figure 3 below shows pass rates for NCEA 3.6 from 2009 to 2013. Two of the categories of this plot benefit from some explanation. Firstly, Absent represents the number of students who did not show up to the exam, whereas Void represents those who are abstaining from a particular AS. As explained earlier in Section 2.2, one of the quirks of the NCEA system is that a student does not need to pass every AS in order to pass or receive an endorsement in a particular subject. If a student feels that they might not pass a particular Ex AS they can choose to skip it and consequently receive a void for that AS, which does not show on their record. If they start an Ex AS (i.e. attempt to answer some questions) but do not gain enough marks the student receives a Not Achieved, which *does* show on their record.

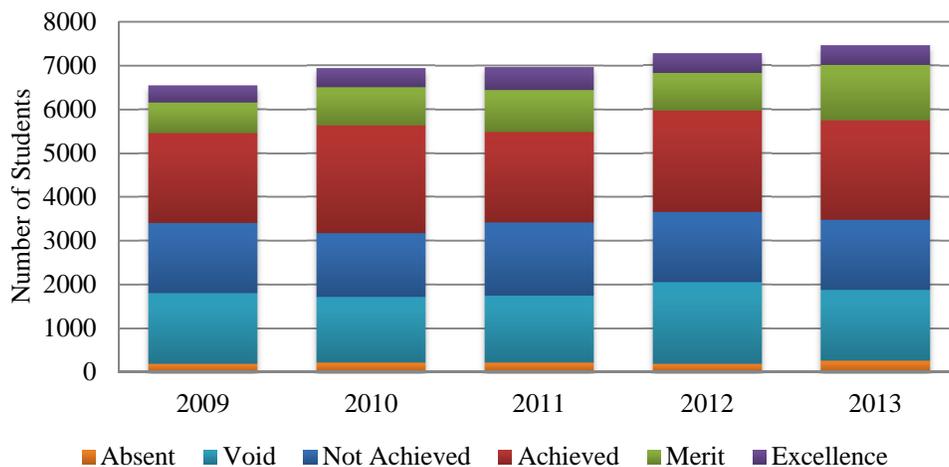


FIGURE 3: NCEA 3.6 PASS RATE FOR THE YEARS 2009 TO 2013

Given that NCEA 3.6 subject essentially forms a prerequisite for the EEE degree, it is of interest to have a closer look at the 3.6 examination results. What stands out in Figure 3 is that about half the students sitting 3.6 are either failing or choosing to skip the electrical Ex AS. Furthermore, if we compare the pass rates of NCEA 3.6 to the other physics Ex AS, 3.3 waves and 3.4 mechanical systems, it is apparent that 3.6 has an unusually high void count. This is illustrated in Figure 4 which shows 22% of students voided the 3.6 (electrical) exam AS compared with only 7% in 3.3 and 3.4 during the 2013 exams. The results for other years are similar. This suggests that a significant number of students consider the electrical component of physics either too hard or not necessary.

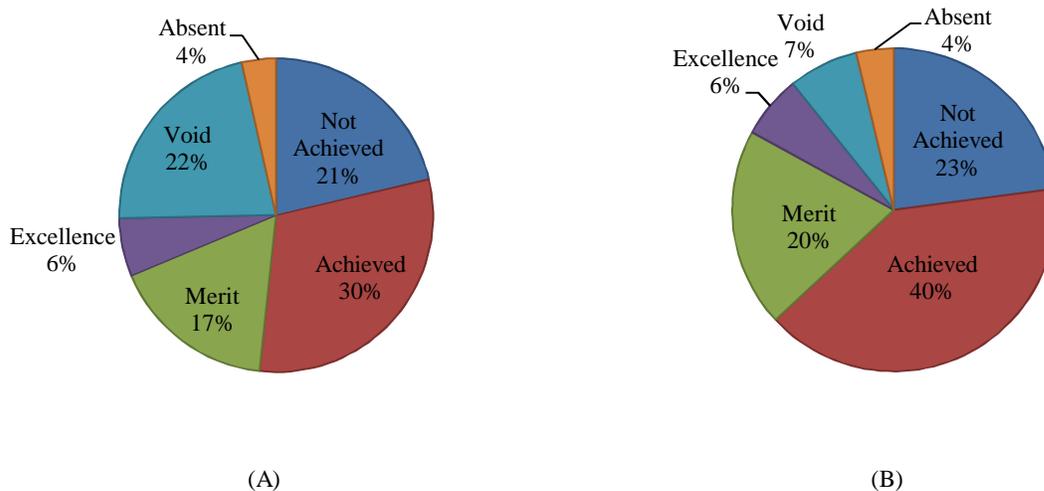


FIGURE 4: NCEA PHYSICS EXTERNAL ACHIEVEMENT STANDARD RESULTS 2013 (A) 3.6 ELECTRICAL (B) 3.3 WAVES AND 3.4 MECHANICAL

4 TERTIARY DIPLOMAS AND UNDERGRADUATE COMPLETION TRENDS

Moving on from secondary school, we investigated the trends in completion rates for electrical related tertiary qualifications up to level 8 (BE Hons) in the New Zealand Qualifications Framework. Figure 5 shows completion rates for electrical related Certificates and Diplomas and Bachelors and Honours degrees from 2003 to 2012. The data represents electrical and related engineering studies including electrical, electronic, computer, communications and related topics. Due to uncertainties around reporting and the available data, the Tertiary Sector Performance Analysis team from the Ministry of Education were unable to provide us data that would allow us to identify completion trends by specialised discipline. Nevertheless, it is apparent that following a period of decline until 2006, the number Certificates and Diplomas completions has increased by an average of about 12% per annum. Meanwhile, the number of Bachelors/Honours completions dipped a ten year low point in 2009. This coincides with the 2005 dip in Year 13 Physics and Calculus enrolment observed in Figure 1 because engineering degrees take four years to complete, and most students are likely to commence their tertiary education following completion of Year 13. As explained in Section 2, USs usually lead to vocational skills and there are no USs offered as part of Level 3 Physics. Hence, students

completing Certificates and Diplomas are less likely to have enrolled in Year 13 Physics or Calculus. It is therefore, the authors' assertion that the NCEA 2005 dip has affected the number of tertiary students completing their Bachelors/Honours degrees.

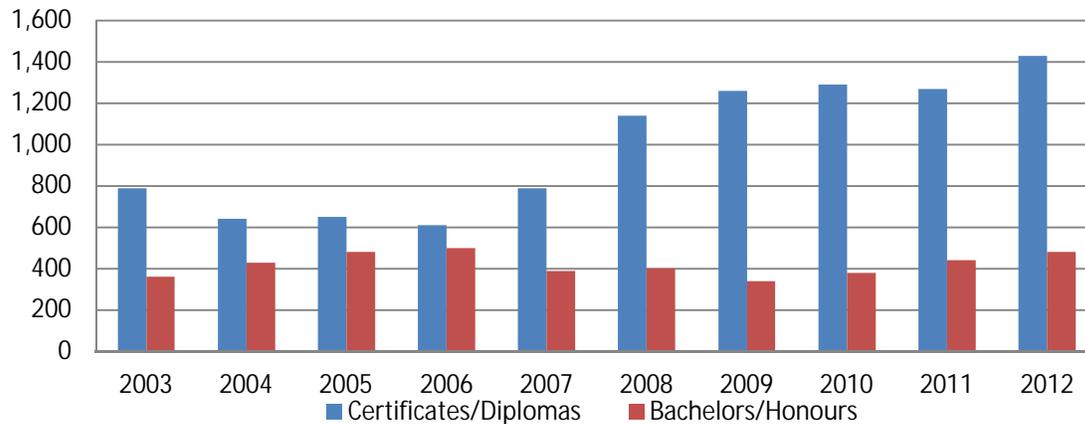


FIGURE 5: NEW ZEALAND TOTAL COMPLETED DEGREES (ELECTRICAL)

5 SECONDARY TEACHERS FOCUS GROUP

The EPECentre has commenced focus group workshops with Physics teachers from five secondary schools to clarify anecdotal and factual research findings before investing in action orientated Outreach programmes. The focus group workshops also engage those schools who are likely to participate in Outreach programmes early on in the process.

Following a few informal meetings and discussions with secondary school Physics teachers, the EPECentre hosted its first Outreach focus group workshop in February. Teachers from five Christchurch based secondary schools actively participated at the workshop and provided their valuable perspective. The following is a summary of findings from the first focus group workshop.

- NCEA assessments in support of electrical engineering are based on outdated technology and need to be updated to suit modern environments that appeal to secondary students. For example, resources consisting of cathode ray television technology examples can be updated to refer to LED TV or smart phone technology.
- Most schools teach electricity (NCEA 2.6 or 3.6) towards the end of the academic year to enable students to remember the content prior their external NCEA examinations. This is because NCEA 3.6 is usually considered to be the most difficult of the three external topics. However there is often less time to teach it at the end of the academic year.
- Students find concepts related to mechanics (NCEA 3.4) and waves (NCEA 3.4) easier to understand and therefore more exciting compared to electricity.
- Most secondary schools are not equipped with sufficient amount of resources such as functioning oscilloscopes to run demonstrations and/or experiments of electrical circuits.

- Schools are in need of simple and reliable circuits that are easy to set up for class room demonstrations and experiments. Teachers have 45 minutes available to them and circuits that often do not work during demonstrations can cause delays.
- Students enjoy their outreach visits to UC laboratories and are likely to remember them for some time. However, the theoretical aspects of UC demonstrations are not usually covered until the end of the year. UC staffs' explanation of electrical systems may not be well understood by most students at the time of their visit. It also needs to be relevant to their 3.6 curriculum.
- Secondary school Physics teachers are interested to work together with the EPECentre, UC to develop resources and teacher refresher training programmes in support of NCEA 2.6 and 3.6.

The secondary teachers' perspective provides valuable insight, and the EPECentre aims to conduct at least two focus group interviews per year until 2016 to support its outreach programmes. Similarly, understanding influencing factors and motivations of students who have recently completed their secondary school education and are now pursuing engineering studies is equally important. The following section investigates this.

6 FIRST YEAR ENGINEERING SURVEY RESULTS

As part of UC's first year Bachelor of Engineering study, students are required to take a compulsory ENGR101 'Foundations of Engineering' paper before committing to their choice of professional engineering discipline in their second year (1st professional year) of studies. ENGR101 enrolments provide a good cross sectional sample size of students who retained their interest in sciences and mathematics at secondary level. Understanding their interests, motivations, influencing factors and their choice of specialised engineering career direction helps to focus on areas of investment in support of increasing EEE interest.

Out of approximately 800 ENGR101 students, a total of 112 students were given the opportunity to respond to a survey designed with a total of 21 questions covering three parts: 'General'; 'Motivations for Pursuing Science and Engineering Study'; and 'Career Path'. Respondents were mostly presented with multi choice questions and asked to tick one of the presented options. The surveys were carried out anonymously at the end of class tutorials over a one week period.

6.1 SUMMARY OF FINDINGS

Of the 112 respondents, a vast majority (95%) achieved their secondary school qualification in New Zealand and 85% were either a permanent resident or citizen of New Zealand. Academic resources (37%), close to home (24%) and recreation/social (19%) were the main influencing factors for students to pursue their studies at UC. A relatively small 5% were influenced by reputation and 4% by scholarship opportunities.

Survey results for motivational factors behind pursuing engineering are shown in Figure 6. Careers ‘definitely’ influenced the majority of respondents (62%) to pursue engineering studies. What is of particular interest is that only 17% of respondents were ‘definitely’ and 29% were ‘not at all’ influenced by their secondary school teachers. Similarly, only a small 8% were ‘definitely’ and 51% were ‘not at all’ influenced by their high school careers advisors. Thus, indicating that students who usually choose to pursue engineering studies are career motivated and both secondary school teachers and career advisors have little influence in support of engineering degrees.

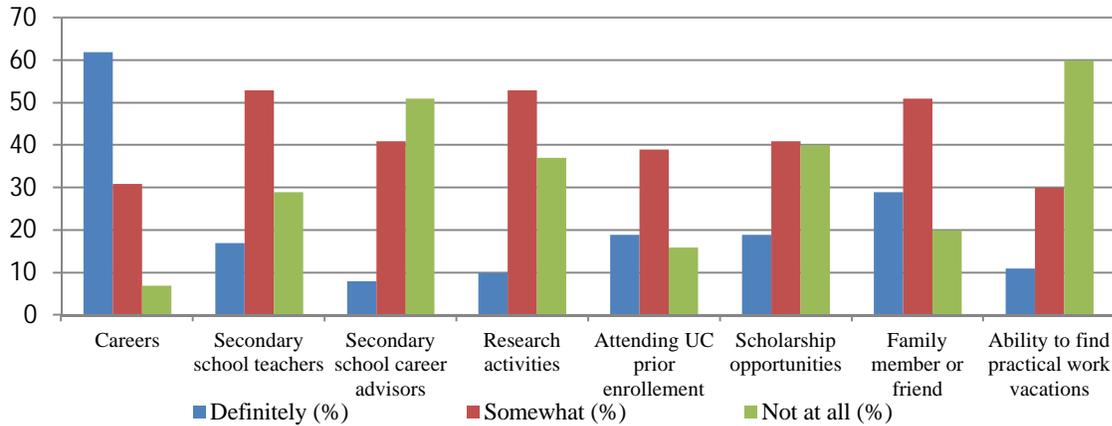


FIGURE 6 MOTIVATIONAL FACTORS FOR ENGINEERING STUDIES

Figure 7 shows the respondents’ preferred choice of study in completion of their engineering intermediate year. Electrical and Computer (11%) is a third equal choice of study following Civil and Natural Resources (35%) and Mechanical (22%) engineering degrees. A considerable proportion of (8%) had not decided their choice of study and some may choose to pursue EEE. 8% of respondents were interested to work in the electric power industry after completion of their undergraduate studies, 48% were not and 44% were ‘not sure yet’.

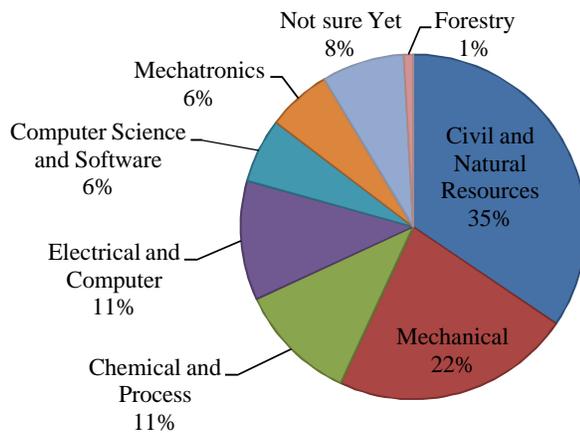


FIGURE 7 DEGREE PREFERENCES OF THE 1ST YEAR ENGINEERING STUDENT SAMPLE

7 GLOBAL PROBLEM

The issue of reversing the declining trend of graduates with electrical engineering skill set is not an isolated case for New Zealand. In recent years, Universities in the United States of America (USA) have also observed declining enrolments in engineering and EEE related degrees with the number of Engineering and Computer Science Bachelor's degrees dropping by over 11% between the 2003-2004 and 2007-2008 [5]. Universities have also observed an increasing number of ill prepared students who have little prerequisite knowledge about their major [6]. Similarly, decline in graduating engineers have also been observed in Australia, European countries including Spain and established Asian countries like Japan and Singapore [7]. To address this issue in the USA, education providers and the industry initiated a number of programmes including those supported by over US\$260 million of public-private investments as part of the "Educate to Innovate" campaign for Excellence in Science, Technology, Engineering & Math (STEM) [5].

8 CONCLUSION

This paper commenced by reviewing the NCEA and identified that secondary school students have the option of selecting their assessments within their chosen subjects in such a way that it gives them the option of excluding to participate in the NCEA 3.6 (electricity) assessment. Although the secondary school Calculus and Physics enrolment trends are rising, a decline in enrolment coincided with the introduction of NCEA Level 3 replacing Bursary examinations. Whilst enrolment numbers in Physics have recovered since, we have identified that approximately 50% of the enrolled students are either not achieving or choosing to not participate in NCEA 3.6 "Demonstrate understanding of electrical systems" examination.

Following a focus group workshop with secondary school teachers we can conclude that students find electricity difficult to understand and are likely to choose alternative options in an effort to gain higher achievement certificate and course endorsements. Teachers are in need of resources and training programmes to learn or retain their knowledge of electrical systems and subsequently teach and inspire students. We also identify that engineering students are motivated by careers and only a small proportion are influenced by their secondary schools teachers and careers advisors to pursue engineering studies.

The available literature reviewed as part of this research suggests that New Zealand is not isolated to declining EEE graduates and a number of outreach and education programmes have been implemented as a result. The EPECentre and the University of Canterbury with support from the Power Engineering Excellence Trust (PEET) has been working on outreach and educational initiatives including workshops, tours, camps, tertiary scholarships, and sponsorship of competitions. However, the key issue identified in this paper is that a programme that specifically addresses the needs of understanding electricity at secondary level and subsequently reducing the number of NCEA 3.6 'voids' and 'not achieved' counts is necessary. The authors would welcome the industry to work together and address this issue.

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