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Issues and Challenges in Engineering Education and the Future Outlook of the Engineering Profession in Australia*

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Australia is presently experiencing a skills shortage in the engineering profession, so much so that this has led to the listing of the specialities of civil, chemical, mining and petroleum engineering on the *Migrant Occupations on Demand List*. This raises concerns and has serious implications for employers of engineers and engineering academics. In this article, the authors attempt to discuss the cause behind this problem and why this is happening in Australia. Raising awareness of the importance of engineering studies in the national education system at the primary, secondary and tertiary levels and promoting engineering as career prospects are crucial steps to remedy the current situation. Australia operates on a fee-based education system to remain competitive in the global education market. However, there are problems with the fee-based system, which is also briefly discussed. The inevitable process of internationalisation and its impact on engineering education in Australia is also presented. A consideration concerning the introduction of a new engineering model, leading to a Masters of Engineering in Australia, to boost the mobility of students and offer internationally recognised qualifications is also carried out in this article. Finally, the authors propose an alternative model, which maybe suitable for the educational market in Australia, to be realised through the establishment of one common or the so-called global engineering curriculum, which can also be used successfully internationally. Such a curriculum would address the issue of offering an internationally recognised programme that is likely to eliminate the need for any recognition and accreditation problems experienced between countries.

INTRODUCTION

There is a general consensus among engineering educators, entrepreneurs, industry and business leaders that engineering education in Australia is in crisis or at least is heading towards this direction. Australia, which has a small population of approximately 20 million inhabitants, is now facing a shortage of professional engineers, which is a cause for serious concern, and the prediction is that this problem will only become worse given the dramatic decline in student enrolment numbers in engineering courses at the university level [1].

An urgent call for more funding to be directed to engineering education is needed in order to address the national skills shortage of professional engineers in Australia. The general perception is that the current government is not investing enough interest and resources in improving the engineering education system in Australia, thus neglecting the future role of this important profession. It is predicted that if the problem with the skills shortage of engineers and the declining student numbers is not resolved, then this could have a directly negative affect on the future

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**As Director of the UICEE, Prof. Z.J. Pudlowski declined to accept the award, which was accepted by Ms D.Q. Nguyen.

economy of Australia because engineers are seen as the creators, innovators, entrepreneurs and key drivers of the economy.

In the following passage, Farrell highlights the important role that engineers play in boosting the economy:

> *Engineers turn knowledge into application. They devise plans, they design products and processes and they deliver results; they are the ultimate doers. Without innovation there is no wealth creation and as a consequence, no economic growth* [1].

Clearly, the preservation and expansion of this profession is vital for the future growth of this nation.

SKILLS SHORTAGE OF ENGINEERS IN AUSTRALIA

Firstly, one has to ask a critical question: why is this happening in Australia?

Presently, in Australia, less than 5% of 24-year old males hold an engineering degree and even lower figures are reported for the opposite gender falling within this same age group. In fact, only six in 1,000 women in this age group have an engineering degree. In comparison, the figures from other developed nations, such as Japan and Finland, are much higher than in Australia [2].

The highest number of undergraduate engineering enrolments in Australia ever recorded was 11,500 in 1997 and this number has been gradually declining [3]. Australia does not appear to be a big player in the mass production and creation of engineering and IT graduates when compared to other populous countries like China or India.

The skills shortage of engineers in Australia could be viewed in two ways, either from an educational or economic perspective.

From an educational perspective, there are a few reasons why Australia is experiencing this skills shortage of engineers. Firstly, the demand and interest for science and mathematics in primary and secondary schools have declined. Without a proper exposure to mathematics and science, which are the fundamentals of engineering education, elementary level students are not expected to fully understand, appreciate or even be aware of what engineering really entails and/or what an engineer really does.

It is obvious that most students, upon the successful completion of their secondary education, are not likely to enrol at the university level in a discipline that they are not familiar with.

Secondly, the declining interest to study engineering at universities among school leavers is not helping the current skills shortage problem. The rapid decline in domestic undergraduate engineering students began in 2001 and the situation will not improve unless significant changes are put in place.

As stated by Hartley,

> *If universities do not give credit or adequate weighting to engineering studies at secondary level, students will not be interested. If there are not enough HECS funded places for engineering Australia doesn't have a hope of overcoming the skills shortage* [4].

The decline is more noticeable in some engineering disciplines, for example, software and telecommunications, and increased in other areas such as civil engineering [5].

When looking at this problem from an economic perspective, the current skills shortage in Australia is mainly due to the resources boom and growth in the construction industry, both locally and internationally. In addition to this, there is a big global demand for engineers around the world, particularly in Asia, the UK and the USA. The shortage of engineers in the areas of civil, chemical, mining and petroleum has resulted in the listing of these engineering professions on the *Migrant Occupations on Demand List* (MODL), which is a list that shows when there is a national shortage of qualified people in a certain profession [3].

Johnston believes that there are a number of contributing factors that are responsible for this downward trend and these include the following:

- Limited perceptions about likely careers in engineering;
- Fear of mathematics;
- Lack of appeal of subject contents, modes of delivery, enthusiasm and base knowledge of teachers [5].

Others believe that students are turning away from engineering programmes because they are now searching *for a broader education and perhaps more choice* [6].

CHANGES IN THE EDUCATION SYSTEM TO ADDRESS THE SHORTAGE CRISIS

To address this issue of skills shortage in engineering, one must first examine the entire Australian educational

system starting from the primary to the tertiary level, and identify where the problems are in the structure and then make the necessary changes to encourage and attract more students to enrol in engineering courses at the tertiary level.

Firstly, the problem needs to be examined at the primary and secondary levels. It would appear that there is a lack of mathematics and science taught in the classroom. Therefore, educators must raise the level of mathematics and science subjects being taught at primary and secondary schools. The exposure to such subjects, which are seen as the fundamentals of any engineering degree, is necessary if students are to have any understanding of what engineering is and what engineering entails.

It is believed that the exposure to mathematics and science subjects at an early age would arouse students' curiosity, interest and enthusiasm for mathematics and science subjects. Moreover, it should help students develop the appreciation, understanding, connection and affinity towards engineering for later study, and prepare students for the transition to study engineering at university. It has been considered by some institutions in Australia that lowering the university entry scores of engineering programmes might increase student enrolment numbers and attract a broader selection of students to study engineering.

The authors are not convinced that lowering the score, and hence the standard of engineering, is the best solution to attract students to engineering courses as the highest calibre of students should be attracted to engineering and not just the average students.

At the tertiary level, a major restructuring and revamping of engineering education, in particular the curriculum contents, is urgently needed in Australia to reflect the changes within the current global market. The new curriculum should have less focus on physics but more on biology, less on technical content and more emphasis on humanities, arts and social sciences, and less focus on analysis and more on synthesis [6]. The new education should be broader in scope, and should integrate knowledge from both the natural sciences and the social sciences and humanities [6].

Further, Boger states that: *Clearly the traditional, almost entirely technically based Australian engineering degree must change and is changing* [6].

In addition to all of these new requirements, the new curriculum must also be consistent, unified and harmonised, and be in accordance and comparable with global standards. More importantly, it must be capable of obtaining international recognition. This leads to the discussion of another important issue in this article, namely, the internationalisation of engineering education.

The other alternative in addressing the nation's shortage of engineers as expressed by Sheridan is to rely on qualified overseas engineers, *either onshore through the immigration program or offshore via outsourcing* [3].

The challenge here, of course, is whether the overseas engineers' qualifications meet Australian national standards and if the foreign qualifications are recognised in Australia so that such qualifications would enable overseas educated engineers to practice their profession in Australia. The other critical issue is to overcome the language and cultural barriers experienced by overseas engineers in Australia.

There has been an increase in the number of skilled immigrants obtaining visas in engineering-related fields from 1,012 in 2001-2002 to 2,636 in 2004-2005. However, these immigrants are largely made up of international students who have studied and successfully completed their education (in engineering-related fields) in Australia and applied for a permanent residence status.

Fox suggests that perhaps removing the Higher Education Contribution Scheme (HECS) fees for engineering degrees might be an incentive to encourage more domestic students to study engineering [7]. This definitely would help, but it is not likely to happen in the near future.

WAYS OF ADDRESSING THE SKILLS SHORTAGE CRISIS IN AUSTRALIA

A list of recommendations was formulated by delegates who attended the recent National Engineering, Science and Technology Skills Summit to address the skills crisis in engineering. The list includes the following suggestions:

- *obtaining more timely and robust data to identify Australia's skills capability and future skills needs;*
- *providing greater support for the teaching of maths and science in schools and universities;*
- *providing primary and secondary students with opportunities to interact with engineers and scientists to spark their enthusiasm and to improve awareness of the rewarding careers available – thereby increasing demand for tertiary courses;*
- *coordinating programs of government, community and professional organisations to provide a solid, technical, experience-based resource for teachers and schools across Australia;*

- *increasing the level of support for university students to improve retention rates;*
- *providing increased support for postgraduate courses to ensure that Australia has an appropriate skills base in advanced technical areas;*
- *addressing workplace culture, remuneration and working conditions to encourage retention of technology professionals;*
- *developing programs to assist technical professionals to upgrade their skills or transfer their expertise into alternative industries;*
- *developing programs to encourage science and engineering professionals to broaden their capabilities to facilitate engagement in the education systems;*
- *supporting initiatives to retain skilled professionals in the workforce* [8].

The points raised in the list all share one thing in common: they all make reference to improving and changing the current education system. This may lead to the conclusion that education appears to be the key solution to the addressing the skills shortage problem.

NATIONAL ENROLMENTS IN ENGINEERING PROGRAMMES IN AUSTRALIA

The national enrolment of students in engineering courses in Australia is presented in Figure 1, obtained from Monash University Planning and Statistics [9]. This line graph represents student enrolment numbers by the field of engineering from 2001 to 2005. This figure takes into account the following:

- Age groups from less than 16 to 60 years or more;
- Attendance mode (internal, external and combination);
- Attendance type (full-time and part-time);
- Course type from non-awards to doctorates;
- Course group (undergraduate, postgraduate and higher education research);
- Field of education (engineering);
- Gender (females and males);
- Students' origins (domestic and international);
- All universities and colleges in Australia offering engineering courses.

There are presently engineering programmes offered in over 30 different engineering disciplines by universities and colleges across Australia.

The overall enrolment numbers show that there has been a steady increase in the enrolments of engineering courses from 48,898 in 2001 to 59,417 in 2005 (although domestic undergraduate enrolments decreased).

It would appear that courses covered in *Engineering and Related Technologies* are the top choice among students, even though the enrolments number has slightly fluctuated from previous years, but it still holds the highest number of enrolments (15,439) in 2005. The next most popular choice among students recorded in 2005 is *Mechanical Engineering* (6,067) follow by *Computer Engineering* (5,237), *Civil Engineering* (5,008), *Chemical Engineering* (3,142), *Electrical Engineering* (4,034) and, finally, *Process and Resources Engineering* (not elsewhere classified) (2,045). However, the figures also show that the decline is happening across some engineering disciplines, namely *Engineering and Related Technologies*, *Mechanical Engineering*, *Computer Engineering* and *Electrical Engineering*, when compared to previous years.

THE INTERNATIONALISATION OF ENGINEERING EDUCATION – THE INEVITABLE PROCESS

Internationalisation, otherwise more commonly known as globalisation, is forcing corporations and educational institutions around the world to think and act globally. As the title of this section suggests, internationalisation is inevitable, which means that no country can avoid or bypass this process if they are to be a competitive player in the global market. The effect is real and is felt across all nations. It has already altered the way that people work and conduct business globally. Also, the impact of globalisation has already had a profound affect on the educational sector. It is putting pressure on educational institutions to modernise, revamp and transform educational materials and policies to meet international standards, offer qualifications that are internationally recognised and produce graduates with global potentials. These are some of the immediate challenges facing educational institutions in Australia and overseas today.

Why has the internationalisation of education become a major concern for educational institutions?

Hallak points out that due to the worldwide spread of the labour market, it has had two consequences:

> *Firstly, the need to compare competencies: how can a company compare a diploma? How can it be sure that certain training has instilled a certain skill? Secondly, the race for excellence: the competition between educational institutions is very likely to intensify and promote the search for the best quality* [10].

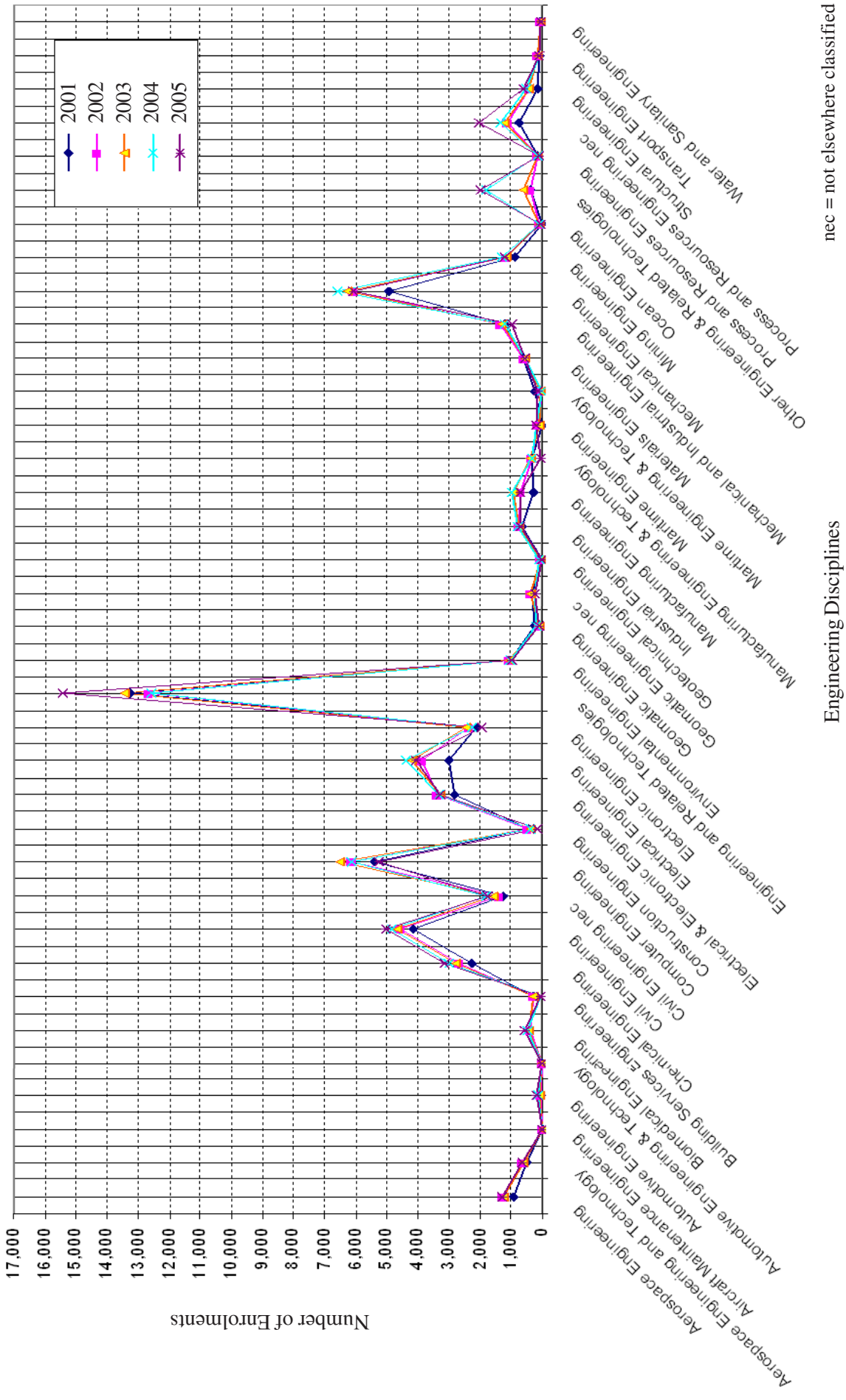

Figure 1: The national enrolment numbers in engineering courses from 2001 to 2005 [9].

Further, Hallak suggests that *the traditional task of higher education in producing the cadres of society should be revised in order to address the new demands and challenges generated by globalisation* [10].

How has this impacted on engineering education in Australia? There have been serious discussions and debates about the problems that arise from the various different standards, accreditation, recognition and diversity of engineering programmes across the globe. These problems would not be an issue if all engineers after graduation would find work and remain making a living in their home countries; but the reality of the problem is that engineering is becoming a global profession due to the impact of globalisation.

Many engineers in Australia are now going offshore to look for work. This provides a great opportunity for many engineers to gain first hand experience in working overseas. The other obvious reason is that many are forced to travel abroad to seek employment due to the shortages of jobs in the local environment or seek better salaries and job opportunities and prospects. In order to overcome this problem, current engineering education in Australia needs to address the issue of establishing the compatibility, comparability and standardisation of qualifications in education and training systems at the international level. The positive outcome is that engineering education in Australia is already on this path of establishing international accreditation through the Washington Accord and other means.

The impact of internationalisation has influenced many Australian universities to tap into the global market by making their programmes more aligned with those universities in Europe in order to promote student mobility, to be seen as a competitor in the global market, as well as attract full fee-paying Australian students' enrolments [11].

ENGINEERING BECOMING A GLOBAL PROFESSION

Increasingly, engineers conduct their work in more than one country and in countries other than where they received their education. The mobility of students and engineers is very much driven by this process of internationalisation/globalisation. Many countries have different laws, cultures, procedures and standards concerning the education and practice of engineering. It is anticipated that the growth of major trading blocs, such as the European Union (EU), the Asia/Pacific area and the Americas, will intensify this process of mobility. Also, instant worldwide communication is a strong catalyst for the development of the global practice of engineering and engineering education.

It is appropriate for the world's engineering profession to recognise this developing situation and to take steps to ensure the orderly transition into the worldwide practice of engineering, and the education of engineers in particular [12]. Yeargan suggests that one method by which this can be accomplished is through the establishment of international accreditation of engineering educational programmes, the recognition of academic equivalency between institutions, and reciprocal agreements between engineering licensing agencies [12].

ENGINEERING CURRICULA IN AUSTRALIA – A NEW PROGRAMME

The University of Melbourne, which is considered as one of the leading Group of Eight (Go8) universities in Australia, is considering the introduction of a new engineering curriculum leading to a Master of Engineering. The proposed model is similar to that of the European model, which may be undertaken in two stages. The first stage is the undergraduate degree (baccalaureate), which can be completed in three years, followed by a Master's degree that requires another two years (the Bologna Model) so that the total programme is completed in five years. The introduction of this new programme came about because there was a demand for the broadening of engineering education, the lack of mathematics and sciences available at high school, the most obvious reason being to offer a qualification that is internationally recognised, and that the extending the tertiary education process is necessary for Australia to maintain its international standing [13].

The opinions expressed by Evans and Marrels, if other Australian universities were to adopt this very same model of a five-year engineering programme at their institutions, are that this would provide a base for further collaboration among the universities to produce an Australian-wide version of the Bologna-like model. This outcome would increase the flexibility and mobility of students between all Australian universities and perhaps even with European universities.

The ramifications of this shift from four years to five years of undergraduate study for an engineering programme are such that it will eventually replace all bachelor engineering degrees, eliminate double degree programmes in engineering and the standard Master's degree programme either by research or coursework, which is typically completed within two years. The standard Masters programme by coursework remains a popular choice for international students and, hence, a substantial source of revenue for the university.

In fact, the statistics show that the number of students undertaking a Master's degree by coursework grew from 1,022 in 2001 to 2,560 in 2004 and, what is

even more surprising, is that more than 80% of the growth was in the field of electrical and electronic engineering [3]. The important question here is: does the introduction of the five-year study programme, leading to a Master's degree in Australia, has a negative impact on this lucrative market? The other question is: does extending the study of engineering to five years deter students from studying engineering and attract them to other disciplines?

PROBLEMS WITH A FEE-BASED EDUCATION SYSTEM

Although there are great benefits and advantages stemming from this new five-year study programme in engineering, the authors are not absolutely certain whether this new model proposed by the University of Melbourne is suitable for the Australian education system, which is predominantly a fee-based education system.

During the most recent years, governments in rich countries, especially in Australia, New Zealand and the UK, have significantly decreased education funding and are forcing many universities to seek private and fee-based funding to remain in operation. In Australia, for example, all universities are charging local students HECS, and hefty educational student fees and charges also apply to international students to obtain a higher degree. The concept of free education was still available in Australia in the early 1980s, but was eventually phased out in 1989 and replaced by fee-based education. The main sources of funding in higher education in Australia are essentially made up of government funding, fees and charges from local and foreign students, as well as HECS.

Australia generates revenue of about $10 billion per year from its education export and attracts a large number of full-fee-paying students, mostly from countries in Asia. The increase in cuts in government educational funding around the world means that commercial and private entities will take a greater role in educational business. Education is slowly becoming a service industry similar to banking, insurance, travel, etc [14]. This seems to be the trend witnessed in recent years in Australia. Fortunately, the situation is not as drastic in those European countries where universities and engineering schools are still receiving large government grants [14]. In light of this situation, the proposed new programme, as advocated by the University of Melbourne, is, perhaps, better suited to cater for higher learning institutions in Europe.

The alternative model strongly advocated by the authors of this article, which maybe suitable for the education market in Australia, is through the establishment of one common or so-called *global engineering curriculum*, which can be used worldwide. Such a curriculum would address the issue of offering an internationally recognised programme, as well as eliminate the need for any recognition and accreditation problems between countries [15].

CONCLUSIONS

Australia is currently facing a skills shortage of domestic engineers across all disciplines. This shortage has come about because of the rapid decline in domestic student enrolments in engineering courses in Australia. The number of enrolments in Australia peaked in 1997 but has declined since. There are a number of contributing factors why students are turning away from engineering. The national curriculum at the primary, secondary and tertiary levels is to blame for this national shortage and changes are urgently needed in the national curriculum to reverse this problem. Moreover, due to the process of internationalisation, Australia is also trying to tap into the global engineering market and offer internationally recognised qualifications and boost student mobility. The University of Melbourne is looking at introducing a five-year programme leading to the Masters of Engineering. The model is similar to that of the European model.

The alternative model, as proposed by the authors, is through the establishment of one common or so-called global engineering curriculum, which would address the issue of offering an internationally recognised programme, as well as eliminate the need for any recognition and accreditation problems between countries. The additional benefits provided by offering a global curriculum have been elaborated on elsewhere [16]. There appears to be general support for the development of the global curriculum in environmental engineering education when taking into account the data collected from an inventory of global engineering educators [16].

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BIOGRAPHIES

Dianne Q. Nguyen graduated with a Bachelor of Applied Science, majoring in chemistry and environmental management, from Deakin University, Australia, in 1994, and then completed her Honours year in 1997 and Masters in Engineering Science (Research) at Monash University, Australia, in 2000.

She has spent time working in research laboratories before entering academia. Since December 1995, she has been with the UNESCO International Centre for Engineering Education (UICEE) in the Faculty of Engineering at Monash University, Melbourne, Australia. She is currently a Research Fellow and finalising her PhD in environmental engineering education.

Her special research interests include environmental engineering, engineering education, sustainable engineering, global education, curriculum analysis and design, statistical analysis, research methods, and women in engineering. Also, she has external interests in Web design and programming in Java and Javascript. In her spare time, she enjoys doing high impact aerobics, weight training, tae-box and reading. Her hobbies include fashion, shopping, computers, travelling, playing music, playing golf and watching movies.

Her awards include: UICEE's *Women in Engineering Education Scholarship* (1997-2000); the UICEE Silver Badge of Honour for her contribution to engineering education and to the operation of the UICEE (1998); the UICEE Best Paper Diamond (First Grade) Award for a distinguished contribution in delivering an outstanding paper to the *Global Congress on Engineering Education* (July 1998); the UICEE Best Paper Silver (Fourth Grade) Award at the *8th Baltic Region Seminar on Engineering Education* (September 2004); the UICEE Best Paper Diamond (First Grade) Award at the *9th UICEE Annual Conference on Engineering Education* (February 2006); the UICEE Best Paper Gold (Third Grade) Award (first place) at the *10th UICEE Annual Conference on Engineering Education* (March 2007); and her latest award, the UICEE Best Paper Diamond (First Grade) Award at the *11th Baltic Region Seminar on Engineering Education* (June 2007). She is also a recipient of the prestigious *Australian Postgraduate Award* (October 2000-October 2003), Monash Departmental Award (October 2000-October 2003) and Monash Travel Grant (October 2001).

She has also served on several national and international engineering education conference organising committees. She has already published close to 50 conference and journal papers.

Ms Nguyen is the current Treasurer of the International Liaison Group on Engineering Education (IL-GEE).

Zenon Jan Pudlowski graduated Master of Electrical Engineering from the Academy of Mining and Metallurgy (Kraków, Poland), and Doctor of Philosophy from Jagiellonian University (Kraków), in 1968 and 1979, respectively.

From 1969 to 1976, he

was a lecturer in the Institute of Technology within the University of Pedagogy (Kraków). Between 1976 and 1979, he was a researcher at the Institute of Vocational Education (Warsaw) and from 1979 to 1981 was an Adjunct Professor at the Institute of Pedogogy within Jagiellonian University. From 1981 to 1993, he was with the Department of Electrical Engineering at The University of Sydney where, in recent years, he was a Senior Lecturer.

He is presently Professor and Director of the UNESCO International Centre for Engineering Education (UICEE) in the Faculty of Engineering at Monash University, Clayton, Melbourne, Australia. He was Associate Dean (Engineering Education) of the Faculty of Engineering between 1994 and 1998.

In 1992, he was instrumental in establishing the International Faculty of Engineering at the Technical University of Lodz, Poland, of which he was the Foundation Dean (1992-1995) and Professor (in absentia) (1992-1999). He was also appointed Honorary Dean of the English Engineering Faculty at the Donetsk National Technical University in the Ukraine in 1995.

His research interests include circuit analysis, electrical machines and apparatus, implementation of computer technology in electrical engineering, software engineering, methodology of engineering education and industrial training, educational psychology and measurement, as well as human aspects of communication in engineering. His achievements to date have been published in books and manuals and in over 350 scientific papers, in refereed journals and conference proceedings.

Professor Pudlowski is a Fellow of the Institution of Engineers, Australia, and of the World Innovation Foundation (WIF), UK. He is a member of the editorial advisory board of the *International Journal of Engineering Education*. He is the founder of the Australasian Association for Engineering Education (AAEE) and the *Australasian Journal of Engineering Education* (AJEE), and was the 1st Vice-President and Executive Director of the AAEE and the Editor-in-Chief of the AJEE since its inception in 1989 until 1997. Currently, he is the Editor-in-Chief of the *Global Journal of Engineering Education* (GJEE) and the *World Transactions on Engineering and Technology Education* (WTE&TE). He was on the editorial boards of the *International Journal of Electrical Engineering Education* (1993-2005) and the *European Journal of Engineering Education* (1993-2005). Prof. Pudlowski was the Foundation Secretary of the International Liaison Group for Engineering Education (ILG-EE) (1989-2006) and is currently its Chairman.

Professor Pudlowski was a member of the UNESCO International Committee on Engineering Education (ICEE) (1992-2000). He has chaired and organised numerous international conferences and meetings. He was the Academic Convener of the *2nd World Conference on Engineering Education*, the General Chairman of the *East-West Congresses on Engineering Education*. He was also General Chairman of the *UNESCO 1995 International Congress of Engineering Deans and Industry Leaders*, and General Chairman of the *Global Congress on Engineering Education*, to name a few.

He received the inaugural AAEE Medal for Distinguished Contributions to Engineering Education (Australasia) in 1991 and was awarded the Order of the Egyptian Syndicate of Engineers for Contributions to the Development of Engineering Education on both National and International Levels in 1994.

In June 1996, Prof. Pudlowski received an honorary doctorate from the Donetsk National Technical University in the Ukraine in recognition of his contributions to international engineering education, and in July 1998, he was awarded an honorary Doctorate of Technology from Glasgow Caledonian University, Glasgow, Scotland, UK. He was elected a member of the Ukrainian Academy of Engineering Sciences in 1997. In 2002, he was awarded the title of an Honorary Professor of Tomsk Polytechnic University, Tomsk, Russia, and was an External Professor at Aalborg University, Aalborg, Denmark (2002-2007). He is listed in 14 *Who's Who* encyclopaedias, including the Marquis *Who's Who in the World*. He has been recently appointed to the Register for External Reviewers of the Oman Accreditation Council (OAC).