Australian Mechanical Engineers: Industries and Attributes

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Abstract*: The US and UK have had significant influence on the delivery and content of engineering programs both globally and particularly on Australia and yet the industrial profile of Australia has historically been significantly different from that of the US and UK. This paper first presents a study into the differences in industrial profile in the employment of mechanical engineers in the US, UK and Australia. This paper then presents key findings from a role-based study that identified the relative significance of a broad range of attributes for the most common mechanical engineering roles in the six industries that employ the greatest number of Australian mechanical engineers*

Introduction

Within one year of the Johnson report (1996) Engineers Australia responded with a radical shift in course accreditation to recommend a broader education and the development of a limited number of broadly defined graduate attributes. These were revised in 1999 and, following the 2003- 2005 developments of Washington Accord Attributes and Professional Development Frameworks, were revised again (Bradley, 2005).

Conceptually the attribute focus is a major breakthrough but the attributes are broadly defined to fit all Australian engineers regardless of discipline. Engineering schools are encouraged to seek industry input to give greater definition to these attributes and in this regard the major input is from the engineering school industry advisory panels. However the views of any professional engineer are subjectively influenced by his/her own unique professional formation.

Arguably the most significant attribute of any professional engineer is the knowledge base. In Australia that is heavily influenced by the UK and the US due not only to the historic and current economic ties with those countries but also due to the fact that those two countries are internationally the dominant contributors to English language engineering research papers and course text books. And yet there have always been significant differences in industrial profile.

This paper first presents the results of an investigation into the current differences in industrial profile for professional mechanical engineers employed in Australia compared with those in the UK and US. It then presents and analyses a role-based attribute study based on the most common Australian professional mechanical engineer roles. This study also requested the role respondents to evaluate the typical attribute level of new graduates relative to the requirements of that role.

Industry profile

The Australian industry profile is necessary to address the differences between the Australian profile and the US and UK profiles. It is also a necessary part of a role-based study into relative attribute significance which will be discussed later. Unfortunately Rice (2001) states that there are no reliable data to indicate the distribution of engineers by specialism in Australia however he used data from the APESMA Professional Engineer Remuneration Surveys (APERS) to provide the best estimate of the change in distribution of engineers by specialism between 1989 and 1999.

The Research and Surveys Unit of APESMA provided our study with raw data taken from a number of years of APERS data which drew from both Engineers Australia and APESMA membership. They also provided raw data from the annual Graduate Engineer Surveys (GES) of their associate members following graduation.

Rice (ibid.) stated that in both organisations there has been a past tendency for civil engineering to be better represented than the other engineering specialisms. In addition Dominic Angerame, Research and Surveys Manager of APESMA, confirmed that historically APESMA has been better represented in large organisations. This is manifest in better membership representation in the larger private companies, but representation in the government sector is particularly significant and will appreciably affect the industry distribution statistics. Lloyd (2001a) reported that the proportion of all engineers in the public sector had plunged to 17% by the year 2000, yet the proportion of public sector respondents in the 2002 APERS data remained at 45%. The proportion of mechanical engineers in the pubic sector is much less than other major engineering disciplines and in the 2002 APERS was shown to be about half (22.6%).

Thus the sample populations in the APESMA surveys may not be truly representative of their target populations. That is, they suffer from *coverage error*. Other statistical data sources were then considered to try to estimate this error. As mechanical engineers form only a small proportion of the data collected the small sample population of graduate mechanical engineers in the Graduate Engineer Surveys would have led to considerable *sampling error* so the survey results of a number of years were combined.

Table 1: Summary of Analysis of Employing Industries of Mechanical Engineers & Graduate Mechanical Engineers

(All) Mechanical Engineers		**Graduate Mechanical Engineers**		
Industry	**% APERS**	**Industry**	**% GES**	**% GDS**
Consulting and Technical Services	16.2%	Consulting	15.6%	16.4%
Transport Equipment	12.6%	Mining	9.7%	8.5%
Electricity and Gas Supply	8.1%	Transport Equipment	9.2%	-
Mining and Quarrying	6.7%	Defence	-	4.7% +4.5% = 9.2%
Construction Contract and Maintenance	6.3%	Financial Insurance Property and Business	-	8.5%
Defence	5.6%	Construction	8.1%	4.9%+1.0% = 5.9%
Industrial Equipment	4.7%	Electricity and Gas	6.0%	1.3%+0.8% =2.18%

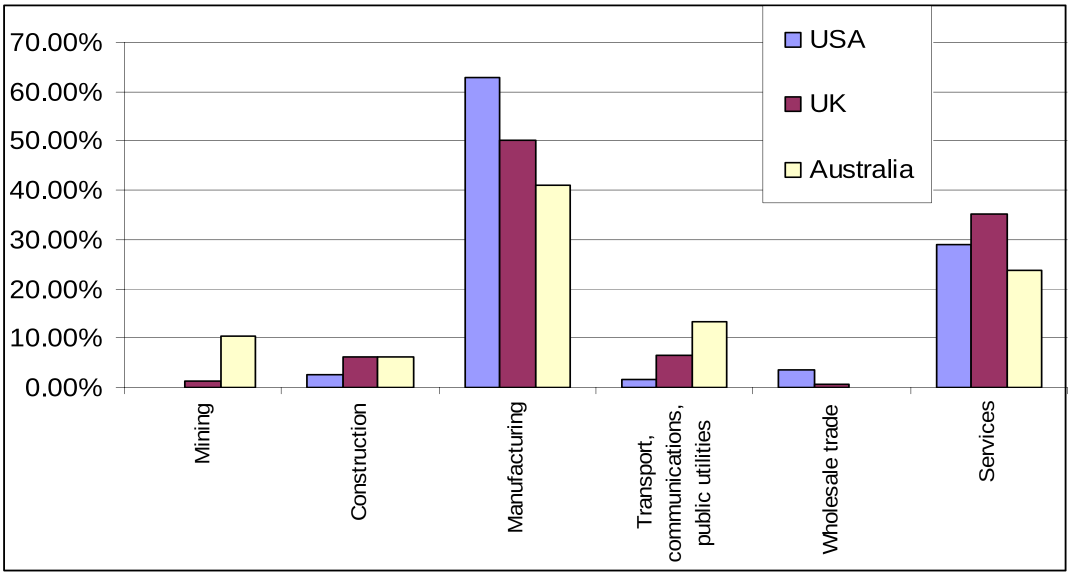
The earlier Engineers Australia 1998 Membership Survey Project (IEAust 1999) did not consider single disciplines and as it was based entirely on Engineers Australia membership it would also suffer coverage error. Further, the 2002 Engineers Australia analysis of the 2001 Australian Bureau of Statistics (ABS) quinquennial Australian Census of Population and Housing (IEAust 2002) also clearly demonstrated that the ABS census does not facilitate determination of the proportion of professional mechanical engineers in any sector with any worthwhile level of confidence. Thus there were no other statistical data to adequately directly support the APERS results of all professional engineers. However as the annual Graduate Destination Survey produced by the Graduate Careers Council of Australia (1999, 2000) has very low coverage, sample and non-response errors, an approximate estimate of public sector bias in the APERS data was facilitated, enabling the APERS results to be adjusted accordingly.

The Graduate Destination Survey also demonstrated the level of accuracy of the GES data. A summary of all three are shown in Table 1. The GDS defence industry data only considered those in the public sector. However the December 2002 APERS data, adjusted to compensate for the over representation of the public sector, showed 47% of those in the defences industry to be in the private sector. Thus in Table 1 it can be seen that 4.5% has been added to allow for those in the private sector. Similar APERS derived adjustments were used to compensate for the omission of public sector graduate employees in the construction and electricity and gas industries.

Comparative accurate data from the UK and US were easier to obtain. The best available source of statistical data on the UK mechanical engineering industrial profile was sample based with significantly greater sampling error than the Australian data but considerably less non-sampling error. Non-sampling error is coverage error, measurement error and response error. This unpublished data had been commissioned by the UK Engineering Council to be included as part of the (UK) Office of National Statistics Labour Force Survey, Spring Quarter 2001.

Table and Figure 2: Comparison of major employment categories of US, UK and Australian mechanical engineers

	USA	UK	Australia
Mining	0.15%	1.42%	10.40%
Construction	2.61%	6.12%	6.30%
Manufacturing	62.89%	50.11%	41.10%
Transport, communications, public utilities	1.68%	6.50%	13.50%
Wholesale trade	3.65%	0.68%	0.00%
Services	28.98%	35.16%	23.90%



The best available source of data on the US mechanical engineering industrial profiles is a survey carried out over a three year period by the National Science Foundation. It is much more comprehensive that either the UK or Australian surveys and is almost a census (at least of all but the smallest employers) and so is considerably more reliable than the UK and Australian data. Great care is taken to minimise all forms of statistical error. A broad comparative overview of the data is presented in Table and Figure 2: Comparison of major employment categories of US, UK and Australian mechanical engineers.

Table and Figure 2 have been adjusted to exclude mechanical engineers employed in the finance, insurance and real estate sectors. This is nearly 21% of UK mechanical engineers compared to only 0.49% US engineers (mainly in real estate). The sample population of the Australian survey did not include engineers no longer practicing in the profession.

Figure 2 clearly shows that two industry sectors are considerably more significant for Australian mechanical engineers than those in the UK or the US: the mining industry and the transport communications and public utilities industry. On the other hand both the UK and the US have a far greater proportion of mechanical engineers in manufacturing. The US has almost 63%; the UK has over 50% whilst Australia has only 41.1%.

Whilst the US and the UK employs a much greater proportion of its mechanical engineers in the manufacturing industry than Australia, of even greater interest to this study are the notable differences in manufacturing industry profile.

The proportion of Australian mechanical engineers employed in transportation equipment (12.60%) is about the same as that for US mechanical engineers (12.16%) whilst the UK proportion is greater at 14.36% (18.2% adjusted). Raw survey data provided by APESMA showed that in Australia this sub-sector is dominated by the automobile manufacturing companies and major tier suppliers.

In the US and UK aerospace forms a major part of the transport equipment sub-sector in which mechanical engineers play a significant role whilst ship building and rolling stock (train) manufacture is a now diminished but still notable component. Thus both countries have greater diversity than Australia within this sub-sector. In Australia there is no other single manufacturing sub-sector that employs close to the same number of professional mechanical engineers. The next largest manufacturing sub-sector is industrial machinery and equipment with 4.7% of Australia's mechanical engineers. With a global oversupply of cars and hampered by a small domestic Australian economy, a heavy reliance on automobile manufacture should be of some national concern.

In the US the industrial machinery and equipment sub-sector employs 18.83% of their mechanical engineers. That's over 50% more than their transportation equipment sub-sector. They also have three more industries that employ a greater proportion of mechanical engineers than Australia's second manufacturing sub-sector: 'electronic and other electric equipment' with 7.36%; 'instruments and related products' with 6.92%; and 'fabricated metal products' with 5.54% of US mechanical engineers. Thus the US manufacturing industry not only employs a much greater proportion of mechanical engineers than Australia but has a healthy diversity of large manufacturing sub-sectors.

The UK has a greater proportion of mechanical engineers in a more diversified transport equipment sub-sector than Australia or the US. Its second manufacturing sub-sector 'basic metals and metal products' employs a further 10.81% of UK mechanical engineers; significantly greater than Australia's second manufacturing sub-sector. Even its third largest manufacturing sub-sector in terms of employment of mechanical engineers, 'industrial machinery and equipment' with 4.92% is marginally greater than the same industry in Australia.

Attribute profile

Global differences

The considerable differences in the industry employer profile of mechanical engineers between Australia and the two nations that continue to have such significant influence on our mechanical engineering courses illustrate the need to develop an attribute profile more focused on the Australian industry profile. There is also evidence that even in the same industries the employment of engineers may be appreciably different in Australia (Lloyd 2001b). Attributes considered significant overseas may be less significant in the Australian context and vice – versa.

Some may argue engineering educators should prepare engineers for the globalised world and thus the argument of whether engineers are better prepared for US or UK conditions rather than Australian conditions would be irrelevant. But there is also an argument for diversity. If the education of large numbers of engineer migrants has been focused on the distinctive needs of their own countries, better diversity as well as an enhanced ability for our graduates to contribute early to their Australian employer's engineering requirements (and thus improved employability) is achieved by developing programs to suit Australian conditions. Of even greater significance, a program that is seen to be more locally relevant provides greater educational stimulus that can better engage the students in deep learning and thus enhance the entire educational experience. It should also be recognised that developing programs for Australian requirements also meets global requirements in that virtually all major industries in Australia are replicated overseas. The effect is only that of reducing the development of attributes that are of less relevance to Australia and providing greater focus on those of greater relevance.

Role-based case study

A role-based case study approach based on the six industries that employ the most mechanical engineers – Consulting Engineering, Transport Equipment Manufacturing, Electricity and Gas Supply, Mining and Quarrying, Construction Contract and Defence – was used to determine the relative significance of attributes for mechanical engineers in Australian industry. Table 1 shows that these industries together account for 55.6% of all Australian mechanical engineers. Minor omissions - limiting Transport Equipment manufacture to automobile manufacture and omitting mechanical engineers engaged directly in the armed services – had minimal impact.

The companies used in the study were those identified from the GES raw data as being the largest recruiters of graduate mechanical engineers and the roles analysed were those identified as being the most significant in those industries. In industries where there were a large variety of mechanical engineering roles with each involving few mechanical engineers a generic role was identified.

Case studies were carried out through interviews with senior engineers and engineering managers responsible for both Stage 1 and Stage 2 engineers engaged in the most frequent mechanical engineering roles in the industries that employ the most significant numbers of mechanical engineers. Seventeen roles were studied. As none of the selected companies/organisation or identified respondents declined to take part in the study the *non-response error* was zero.

The definitions of Stage 1 and Stage 2 engineers are broadly in line with the Engineers Australia definitions: a Stage 1 engineer is a BE graduate with less than three years professional experience and a Stage 2 engineer is one with greater than 3 years professional experience.

There are two dimensions to role-based attribute significance: the importance of that attribute to the role; and the level of skill in that attribute necessary for the role. To avoid ambiguity respondents were asked to consider only the significance of the attribute to that role as required of a stage 1 engineer and a stage 2 engineer regardless of necessary ability level. For graduate ability the requirement was for an assessment of average ability of recent new graduates in that attribute relative to the demands of that role (Ferguson, 2006).

The survey instrument extended the Engineers Australia graduate attributes to 84 attributes by:-

- Breaking attributes down (e.g. communication skills were broken down into various forms of written and oral communication);
- Including attributes more specifically related to mechanical engineering roles (e.g. 3D visioning, dynamic visioning);
- Including a wide range of attributes from numerous past surveys relating to the desired attributes of graduates - both engineering graduates and graduates in general; and
- Including personal attributes (e.g. interpersonal skills and time management).

The attributes also included the ‘engineering knowledge base’ and ‘mathematical skills’ that universally form the core of all undergraduate mechanical engineering degree programs.

For role-based attribute significance a five point Likert was used with the terms ‘no use’, ‘rare’, ‘occasional’, ‘significant’ or ‘essential’. For graduate ability they were ‘none’, ‘poor’, ‘moderate’, ‘significant’ and ‘excellent’ (ibid.).

Results

To facilitate analysis the 84 attributes were first grouped as shown in Table 3. Management, Communication skills and Personal attributes are overall the most significant attributes for stage 1 and stage 2 engineers and in general graduate ability closely matches these attributes. It should be noted that as recruitment is usually based on who best can demonstrate attributes considered most significant for the role, this would raise the average graduate ability assessment for those attributes i.e. the graduates undertaking these roles would most likely have better than average attributes considered relevant to those roles

Table 3: Group Average Ratings

	New Graduate Ability Groups	Average Rating	Stage 1 Engineer Attribute Groups	Average Rating	Stage 2 Engineer Attribute Groups	Average Rating
1	Mathematics	2.89	Communication	2.92	Management	3.51
2	Personal Attributes	2.83	Management	2.91	Communication	3.48
3	Communication	2.45	Personal Attributes	2.81	Personal Attributes	3.24
4	Management	2.38	Problem Solving	2.79	Problem Solving	3.23
5	Research Skills	2.36	Computer Skills	2.77	Design	3.17
6	Information Sources	2.15	Information Sources	2.71	Information Sources	2.97
7	Problem Solving	2.15	Design	2.65	Business Skills	2.83
8	Computer Skills	2.09	Engineering Drawing	2.51	Mechanical Engineering Knowledge Base	2.77
9	Mechanical Engineering Knowledge Base	1.97	Mechanical Engineering Knowledge Base	2.32	Engineering Drawing	2.45
10	Design	1.95	Business Skills	2.25	Research	2.42
11	Business Skills	1.80	Research	2.16	Computer Skills	2.29
12	Engineering Drawing	1.66	Mathematics	1.78	Mathematics	1.78

Personal attributes

This is a grouping of largely unconnected attributes mostly from the ‘affective domain’ (Bloom’s Taxonomy classification). The personal attributes used in this study were Modern language skills, Reliability, Conscientiousness (a disciplined approach to work), Time Management, Interpersonal (social) Skills, Flexibility, and the Expectation and Capacity to Undertake Lifelong Learning. All of the personal attributes apart from Foreign Language Skills were considered essential in most roles for a stage 2 engineer. In stark contrast, as English increasingly becomes the de facto international language, the significance of Foreign Language Skills was considered rare overall and significant in only one role. The removal of this attribute from the personal attribute group would result in this group being the most significant group for stage 1 and 2 engineering roles and also for graduate abilities. With the exception of Time Management the remaining graduate attributes were considered significant or better. Graduate ability in Time Management was rated moderate to significant. However one respondent suggested this still represented a considerable improvement over the last decade and may be due to increasing casual employment of students to support their studies.

Mechanical engineering knowledge base

The relatively low significance rating of the mechanical engineering knowledge base is due to averaging the significance of each mechanical engineering subject specialism across all roles. The real significance of the mechanical engineering knowledge base is demonstrated by careful analysis of the underlying data. For most roles at least one mechanical engineering subject specialism is considered essential. The subject specialisms of Stress Analysis, Applied Mechanics, Engineering Management, Fluids and Thermodynamics were all considered essential in three or four stage 2 engineering roles and Manufacturing was essential in five stage 2 engineering roles. Engineering Management had the highest average rating. However the overall average rating for graduate ability is less than moderate and should be of concern.

A more reliable overall assessment of the significance of the mechanical engineering knowledge base can be inferred from those problem solving and design group attributes for which the mechanical engineering knowledge base is an enabling attribute. These include: broad engineering knowledge base; application of science and engineering fundamentals; recognise when to use engineering analysis; to know when to call in a specialist; and in-depth discipline knowledge. All of these were considered significant or essential for most roles whilst at best rated moderate for graduate ability. This indicates a failure to respond effectively to the Johnson report recommendation of a broader engineering education.

Mathematics

Like the Mechanical Engineering Knowledge Base, Mathematics is traditionally and universally the core of university mechanical engineering courses. In contrast the average graduate engineer's mathematical skills are considered significant (relative to the requirements of the role) in all forms of mathematics but statistics, whilst their average direct use in engineering practice was regarded as less than occasional; reflecting increasing use of computer based analysis in professional practice. The traditional practice of developing subject specialist conceptual knowledge through rigorous mathematical analysis in lectures and assessment ensures and demands excellent mathematical skills but may also be a cause low completion rates. Greater use of active learning and educational technologies should better engage the students and develop conceptual knowledge more effectively.

Entrepreneurship

Surprisingly overall role related assessments of attributes such as entrepreneurship, innovation, creativity, generally rated less than significant. Graduate abilities for all of these competencies were rated only as moderate. And yet for the 18th and early 19th century British engineers probably their most essential attributes would have included political awareness (to muster financial backing for their projects) and entrepreneurship. Neither of these attributes reached a significant rating in our study and yet entrepreneurship is essential for national prosperity, development and growth (Hindle and O'Connor 2005). The Allen Consulting Group (2006) also identifies the growing importance for Australian business of innovation, creativity and 'tailoring' over the next decade and the implication that design will drive economic growth through development of high-value products that can better compete in the global economy.

Improved attributes

The ratings of many attributes previously considered deficient such as communication skills (Prescott 1992; Burtles 1992), lifelong learning skills (Prescott 1992; West 1998), team skills (Prescott 1992; Fairclough 1995), and time management (Burtles 1992) are now rated substantially better than moderate or significant. Graduate abilities in other attributes previously assessed as deficient such as intellectual curiosity, independent thought, problem solving, and critical thinking (Prescott 1992) have improved slightly to a moderate level.

Key Conclusions

The mechanical engineer industry profiles in the US, UK and Australia show that Australia is distinctly different. Because of this it was important to explore in detail the attributes required by Australian industry for consideration in course development. There is also value in developing diversity between Australian providers of mechanical engineering programs through closer links with locally based industries.

The attribute focus in course accreditation has led to significant improvements in some attributes of previous concern. However the graduate mechanical engineering knowledge base attribute is now generally rated as moderate or less and should be of new concern. Whilst some put the blame for this on the focus on attributes replacing the focus on knowledge base, appropriately designed courses and the greater use of newer educational practices such as active learning and the use of modern educational technologies should better enable the development of these attributes as well as improve the conceptual the mechanical engineering knowledge base. Assessment drives learning and whilst directed towards the conceptual knowledge base the form of that assessment can also support the development of the required attributes.

The low overall role related ranking of the mechanical engineer knowledge base was due to most roles having only one or two subject specialisms rated as essential. However attributes for which the subject specialisms are enablers, such as Broad Engineering Knowledge Base, were highly ranked. This supports a Bologna–like 3+2 model that develops a broader engineering knowledge base in a first degree and advanced knowledge in selected specialist topics appropriate to the intended mechanical engineering career role in a subsequent master's degree.

Of national concern is the low average role rating for attributes such as entrepreneurship, creativity and innovation, for without a greater focus on the development of these attributes it will be increasingly difficult for many industries to compete with the lower pay structure in the developing economies.

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