Re-engineering Engineering Curricula for Tomorrow's Engineers

William Bons
RMIT Master in Engineering Management Program, Melbourne, Australia
wbons@bigpond.com.au

Allan McLay
RMIT University, Melbourne, Australia
mclay@rmit.edu.au

***Abstract**: Outlines research into how engineering students could be better prepared to apply tomorrow's new technologies as they emerge.*

A range of 27 'Attribute' skills and 'factors' and 'organisations' which impact engineering curricula development were identified. Key stakeholder groups, i.e. academic staff, industry human resources staff, senior engineering (supervisory) staff, and engineering graduates in the workplace, were surveyed through 2002. In particular the research examined 'gaps' between attribute 'importance' and 'levels of preparation' which graduates felt they had received.
The majority of attribute skills were deemed important by stakeholder groups, although surprisingly the attributes 'environmental awareness' and 'economic fundamentals', both ranked low. The following 4 attributes show high gaps between preparation and importance based on the graduates' views: 'A sense of accountability for actions'; 'Interpersonal skills'; 'Skills to advocate and influence'; 'Communication skills'.

***Keywords**: attribute skills, emerging technologies, engineering curricula.*

Introduction

Innovation is an important driver of sustainable economic growth and employment, and links engineering education to a country's wealth creation. Engineers today operate in a competitive environment where their employers are likely to be either a global company or at least a company subjected to global competitive pressures. Thus today's engineers need to be equipped with various attributes and motivation to help their employers innovate and succeed.

This paper presents findings of research on determining how tomorrow's engineering graduates could be better prepared to learn and apply tomorrow's new/emerging technologies in increasingly global industrial contexts. Key research questions addressed included:

1. What are the opportunities for improvement in engineering education such that engineering graduates are better prepared for tomorrow's new emerging technologies?

2. What are the influencing factors and their interrelationships, which impact engineering curricula development for undergraduate engineering studies?

The 1996 IE Aust. study into engineering education identified that graduates need to have a broader education and be more adaptable to situations in the contemporary workplace. It found that graduates needed to go beyond the traditional core of mathematics, science and technical subjects, to be more socially, culturally, environmentally, and economically sensitive, to mention a few of society's expectations. The IE Aust. findings (Johnson, 1996) concluded:

- "There was an urgent need for a fundamental paradigm change in engineering education."

This was due to two principle reasons:

- "Technological pressures from the impact of new emerging technologies, particularly in the areas of information systems."
- "Social pressures from the need for sustainable development. This was impacted by the growing social awareness of the need to preserve living style for future generations."

The report also concluded:

- "Graduates needed to be more outward looking, and assume expanded responsibilities."
- "Engineers needed to be better communicators and be more politically aware."
- "They needed to have their technical decisions to be made, understood and communicated with sensitivity, especially across cultural boundaries."

Whilst this emphasis on broader education for engineers is acknowledged by a majority of industry and academia, it also presents an opportunity to research the current views of major stakeholders, to see how well the combined efforts of our universities and industry have faired since the 1996 IE Aust. study findings and recommendations.

The research hypothesis is illustrated in a systems diagram in Figure1, and is stated as follows:
'There is a need for a greater balance between teaching undergraduates more new technologies as each one emerges, and the need for undergraduates to experience and develop various attributes which will make the undergraduates more adaptable and more relevant to industry and society's expectations'.

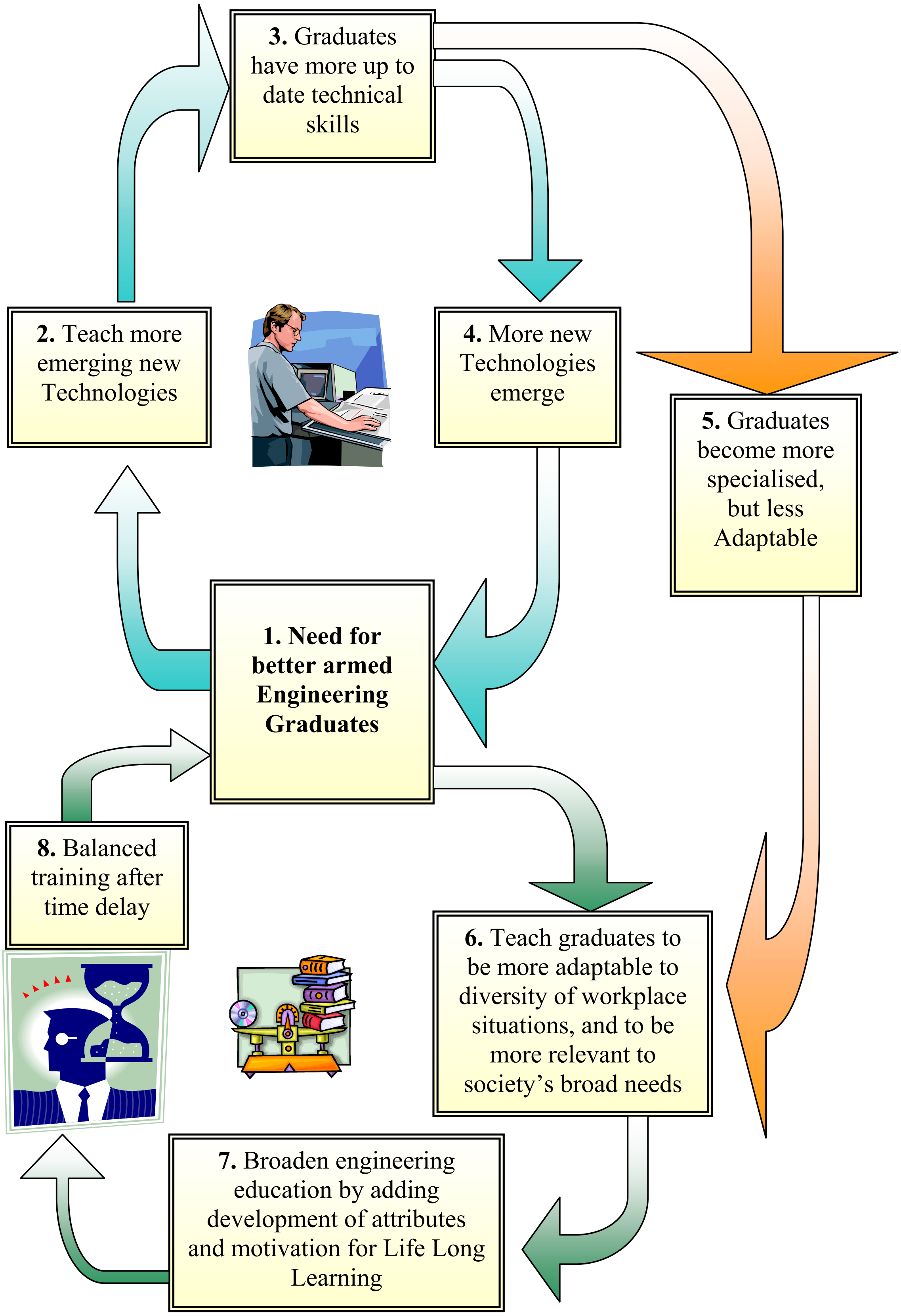

Figure 1: Systems Model of Hypothesis

Identifying Key Factors

Initial activity in the research involved a literature review to identify key factors and discussion points relevant to today's engineering education and curricula development. The review addressed the following topic areas:

- Globalisation pressures on engineering
- Culture change in engineering education
- Engineering curriculum development
- Holistic approach to engineering education
- Life long learning
- Desired attributes for engineers
- Assessment of curricula outcomes
- Engineering coalitions in USA
- Australian experiences
- Industry links
- Engineering graduate numbers

Apart from the IE Aust. study, many publications reviewed were quite narrow, or specific to particular 'engineering' topics. Not surprisingly, given the context of a discipline with multiple major fields of study and debate. The review did however highlight a gap in the overall helicopter view of developments in engineering education.

New engineering courses and existing course modifications relating to new streams or technologies are generally carried out with rigorous debate via both academic staff and industry representatives on course committees. University policies and scheduled course reviews and procedures ensure this. The potential gap identified is related more to general industry views on effectiveness of engineering education in terms of graduate attributes. The research identified a comprehensive list of attributes as recommended by Chang (1998).

The research also identified gaps between Australian universities and developments overseas. Australian universities appear to be quite well covered by internal quality control procedures, providing feedback from current or recently graduate graduated students. However, there appears to be little or no feedback data available from graduate engineers after some time in the workplace, or from industry that employs the graduates. It appears that this broader feedback would be desirable and be more customer focused. Feedback on engineering education needs to go beyond how students feel their course was presented at the time.

The review also addressed an expanded assessment of curricula outcomes that occurs at some universities in the USA. (MIT, 2000) (Kasuba & Vohra, 2000) Other than the IE Aust. 1996 review in engineering education, there appears to be little Australian research data on broader assessments, recommendations, or regular surveys of graduate engineers in the workplace.

Preliminary Interview highlights

Interviews were held with academic and industry staff prior to initiating the main research surveys, to obtain further background on issues and factors influencing engineering curricula development. The following points are from these interviews.

- Whilst there was a perceived gap in understanding of engineering education needs between industry and academia, there are some successful models used locally and overseas for undergraduates gaining workplace experience.
- Academic staff have difficulties relating to industry pressures. They have their own internal pressures and priorities.
- Industry needs to be more supportive toward universities by way of contributing funds for joint research programs and for participation in engineering curriculum development.
- Universities must be able to establish an outcomes oriented view, understand the market and target the necessary graduate competencies or attributes.
- Australian universities make extensive use of course experience type questionnaires for feedback on course delivery, subject content etc. and routinely analyse this information.
- The Australian University Quality Agency (AUQA) conducts regular audits of Australian universities.
- Australian universities rarely survey engineering graduates in the workplace, or their employers, on the relative success of their tertiary education.
- Problem-based learning is increasingly replacing traditional classroom teaching. Universities are equipping students with base knowledge whilst emphasising how to solve problems. Some universities are reducing classroom contact hours.
- Project experiences are important for future degrees where generic attributes can be developed. Projects need to be real industry projects.
- Project work builds generic attributes, however there are issues associated with assessing some of the generic attribute skills such as ‘leadership’ and ‘teamwork’.
- There is a convergence of workplace learning and educational institutional learning. Workplace learning develops problem solving, creativity, initiative and other attributes.

Survey statistics

Table 1 summarises the survey groups covered in the research, sample sizes and the survey return rates. Industry staff participating in surveys 2 & 3 are principally from the automotive industry.

Survey Category Description	Survey Reference No.	Delivery Method.	Qty's of Surveys delivered	Number of valid returns	% valid returns
Academic staff surveys	Survey 1	Hand out at interviews	18	14	78%
Industry HR staff surveys	Survey 2	Hand Distribution	9	9	100%
Industry senior engineering staff surveys	Survey 3	Email Distribution	40	25	63%
Graduate / alumni surveys *(Mail out minus 18 returned incorrect address)	Survey 4	Mail out via RMIT Alumni (485 total)	467*	45	10%
Academic and industry staff via organisations	Survey 5	Email	18	5	28%
Total			552	98	18%

Table 1: Survey Statistics

EMPLOYMENT STATUS	**Qty**	**%**
Full time:	41	91%
Part time:	1	2%
No current job:	1	2%
Information not provided:	2	4%
Total	***45***	***100%***
INDUSTRY CATEGORY	**Qty**	**%**
Agriculture, Forestry & Fishing	1	2%
Mining	1	2%
Manufacturing (Incl. Automotive/ aerospace design)	27	60%
Electricity, Gas & Water Supply	2	4%
Construction	4	9%
Communication Services	1	2%
Property & Business Services	1	2%
Government Administration & Defence	6	13%
Personal & Other Services	2	4%
Total:	***45***	***100%***
YEAR OF GRADUATION	**Qty**	**%**
1989	4	9%
1990	5	11%
1991	2	4%
1992	4	9%
1993	7	16%
1994	6	13%
1995	6	13%
1996	6	13%
1997	2	4%
Information not Provided:	3	7%
Total:	**45**	**100%**

Table 2: Engineering graduate (Alumni) survey respondents profile

Table 2 details the employment profile of the graduates (Alumni) surveyed. 91% of the respondents in this survey group had been in the workforce for a minimum of 5 years. The survey was directed to 467 Mechanical or Aerospace Engineering Alumni. Industry employment categories used are taken from the Australian Bureau of Statistics categories.

Research findings

Importance of graduate attributes

Research surveys asked the respondents to rate the relative levels of importance of each of 27 generic attributes. These were in turn ranked in order of importance. Table 4 shows combined (and weighted) ranking on importance as well as the individual group rankings. The top 5 attributes as ranked by the respondent groups are summarised in Table 3 below.

Academic Staff	Industry Human Resources (HR) Staff	Industry Senior Engineering Staff	Engineering Graduates (Alumni)
1. Communication skills	1. Teamwork skills	1. Problem solving skills	1. Accountability
2. Problem solving skills	2. Mathematics/ science fundamentals	2. Listening skills	2. Teamwork skills
3. Accountability	3. Communication skills	3. Communication skills	3. Communication skills
4. Ability to work in cross disciplinary teams	4. Interpersonal skills, and	4. Accountability, and	4. Interpersonal skills, and
5. Interpersonal skills	5. Listening skills	5. Writing skills	5. Skills to advocate and influence

Table 3: Top 5 Attributes by Respondent Group

Further comparisons between rankings of the groups surveyed include the following:

- Academic staff ranked ‘**listening skills’** at 13th , other groups at 7th or higher.
- Industry HR staff ranked a ‘**sense of accountability for actions’** at 18th, other groups at 4th or higher. Engineering graduates as the most important attribute.
- Senior engineering staff ranked ‘**teamwork’** at 10th, academic staff at 8th, however industry HR and engineering graduates at 1st and 2nd respectively.
- Engineering graduates in the workplace ranked ‘**mathematics/ science fundamentals’** at 16th, other groups in the top 10.
- Engineering graduates ranked ‘**advocate and influence skills’** attribute at 5th in importance, other groups at 20th to 25th in importance.
- Engineering graduates in the workplace ranked ‘**management skills**’ 8th, other groups between 17th and 24th in importance.
- Industry HR staff ranked ‘**speaking skills’** 9th , other groups between 14th and 21st.
- Academic staff ranked ‘**environmental awareness’** at 14th, and the three other groups between 24th and 26th (out of 27).
- All groups ranked ‘**awareness of economic fundamentals’** between 23rd and 27th.
- All groups ranked the following attributes very low:
    - Societal skills
    - Skills in handling cultural diversities

- Foreign language skills
- Environmental awareness
- Visionary skills for own career path.

Table 4: Comparison of individual survey group rankings plus combined and weighted ranking on importance of attributes.

Attribute * Ranked for "Combined-weighted" mean (X = mean rating score)	**Combined groups**		**Survey groups - rankings comparison**			
			Academic	**Industry HR**	**Industry Senior**	**Eng. Grad**
	X	**Rank***	**Staff**	**Staff**	**Eng. Staff**	**Alumni**
Communication skills	4.6	**1**	1	3	3	3
Problem Solving skills	4.6	**2**	2	6	1	6
A sense of Accountability for actions	4.5	**3**	3	18	4	1
Teamwork skills	4.5	**4**	8	1	10	2
Interpersonal skills	4.5	**5**	5	4	7	4
Listening skills	4.4	**6**	13	5	2	7
Ability to work in cross disciplinary teams	4.3	**7**	4	7	8	N/a
Writing skills	4.3	**8**	20	14	5	9
Creative thinking skills	4.2	**9**	6	8	9	11
Problem Based learning skills	4.2	**10**	7	11	13	N/a
Mathematics / Science fundamentals	4.1	**11**	9	2	6	16
Advocate and influence skills	4.0	**12**	25	20	20	5
Information technology skills	4.0	**13**	12	10	15	12
Function productively over Career	3.9	**14**	11	26	14	15
Life Long Learning habit commitment	3.9	**15**	10	13	12	18
Management skills	3.9	**16**	17	22	24	8
Broad education - competency range	3.9	**17**	16	23	16	13
Leadership skills	3.9	**18**	18	21	23	10
Responsibility for personal growth	3.8	**19**	19	12	17	17
Intellectual vitality	3.8	**20**	22	16	11	19
Speaking skills	3.8	**21**	15	9	21	14
Visionary skills for own career path	3.6	**22**	24	19	22	20
Skills in handling Cultural Diversities	3.5	**23**	26	17	18	21
Societal skills	3.5	**24**	27	15	19	22
Environmental awareness	3.2	**25**	14	24	26	24
Economics fundamentals	3.2	**26**	23	27	25	23
Foreign language skills	2.3	**27**	21	25	27	25

Ranking of 1 = most important. **Mean rating score X** 5 = Very Important, 1 = Not important

Levels of preparation for graduate attributes (Graduate's view)

Engineering graduates were asked to indicate the 'level of preparation' they felt they had received during their tertiary studies, as well as the 'importance' against each nominated attribute. As shown in Table 2 above, all of the respondents have been in the work force for 5 years or more (up to 13 years). Hence the respondents were experienced in the workforce and considered qualified to put forward a view on the importance of various attributes. Equally they would be able to reflect on the levels of preparation they had received for each attribute prior to entering the workforce.

The top 5 attributes ranked for level of 'preparation' are as follows:
1. Mathematics/ science fundamentals
2. Problem solving skills
3. Teamwork skills
4. Broad education – competency range, and
5. Writing skills

The lowest 5 ranked attributes for level of 'preparation' are as follows. Results for the higher 4 indicated graduates felt they had received 'fair preparation'. The exception was the attribute 'environmental awareness' for which graduates felt they received 'poor preparation'.
1. Economics fundamentals
2. Visionary skills for their own career path
3. Advocate and influence skills
4. Skills in handling cultural diversities, and
5. Environmental awareness

Gap between preparation and importance of graduate attributes

The research looked at the gap between 'importance' and 'level of preparation received' for listed attributes. The attributes are ranked in order from the largest difference between 'importance' and 'preparation'. This is a representation of the 'gap' ranking or the actual state (level of preparation) verses the desired state (importance).

The top five attributes ranked by gap between 'importance' and 'levels of preparation', as viewed by the graduates, are as follows. The level of importance rankings from academic staff viewpoint are shown in brackets.
1. Skills to advocate and influence (ranked 25th in importance)
2. A sense of accountability for actions (ranked 3rd in importance)
3. Listening skills (ranked 13th in importance)
4. Leadership skills (ranked 18th in importance)
5. Interpersonal skills (ranked 5th in importance)

The top five attributes ranked by importance from the academic staff survey are shown below with gap ranking (graduate's view on gap) in brackets
1. Communication skills (gap ranking 6th)
2. Problem solving skills (gap ranking 21st)
3. A sense of accountability for actions (gap ranking 2nd)
4. Ability to work in cross disciplinary teams (gap ranking 26th)
5. Interpersonal skills (gap ranking 5th).

This indicated three of the top five attributes in importance, as seen by academic staff, ranked in the top 10 for gap for level of preparation received by the graduates.

Factors which influence engineering curricula development

The 'factors' used in the research were identified from the literature review and were surveyed to determine their 'relative levels of influence' on engineering curricula development. Surveys used an attitude scale to measure each respondent's view on the 'level of influence'. Surveying of 'factors' that influence engineering curricula development was limited to academic staff and industry HR staff. The top 10 in order of level of influence are listed as follows:

1. Engineering accreditation authorities
2. Developments in new learning techniques
3. Strategic Planning/ vision (tertiary institution)
4. Industry involvement in curricula development
5. Need for innovation in engineering curricula
6. Staffing levels (tertiary institution)
7. Continuous improvement
8. Staff motivation (tertiary institution)
9. Tertiary institution funding, and
10. Curriculum success evaluations (industry feedback)

It was interesting to note that 'curriculum success evaluations (Industry feedback)' ranked 10th , whilst the use of 'past students (Alumni) survey feedback' ranked 23rd, i.e. almost last.

It could be argued that complete customer feedback on the success of engineering education, could not necessarily be obtained without feedback from both the employer and the engineering graduate. The latter being able to judge the adequacy or otherwise of their tertiary studies and who's views could be just as vital as those of the employers.

Organisations which influence engineering curricula development

The 'organisations' used in the research were identified from the literature review. Academic staff were surveyed to determine the 'relative levels of influence' on engineering curricula development of these nominated organisations. The top 5 ranked organisations for (highest) level of influence on engineering curricula development were found to be:

1. Institution of Engineers Australia
2. Australian Council of Engineering Deans
3. Australian Association of Engineering Education
4. Society of Automotive Engineers
5. Australian National Training Authority

However, these results only provided limited contribution toward understanding engineering curricula development. Determining the relative importance of organisations on engineering curricula development needs to be further researched in the context of their specific roles and contributions.

Conclusions

The literature review identified some potential gaps or opportunities for improvement within engineering education, in particular the opportunity to consider broadening engineering education to expose undergraduates to a wider range of generic attribute skills.

The hypothesis proposed that universities and industry groups needed to make engineering graduates more adaptable to the workplace, and to make them more sensitive to employers and broader community expectations.

Attribute importance

The above findings conclude that the majority of the 27 listed attribute skills were deemed to be 'fairly important' to 'very important' by the individual stakeholder groups. Surprisingly the attributes 'environmental awareness' and 'economic fundamentals', both ranked low in comparison to other attributes. Given today's community expectations, it is disappointing that 'environmental awareness' did not rank higher. Similarly, the 'economic fundamentals' attribute could be expected to be mandatory for budget control in engineering project management, whether for large capital projects through to small project expenditures.

Even though the rankings differentiated between various attributes, the rating scores did not differ greatly from each other. Each of the groups top 5 attributes ranked in the top 8 of the combined results, with one exception. This exception was the attribute 'skills to advocate and influence' which was in the graduate group's top 5, but not in the remaining group's top 5, and was ranked 12th in the combined view.

Learning gap

This study addressed the views graduates had on which attributes had the largest learning gaps from their tertiary training, based on their early years of workplace experience. The gap represents the difference between 'importance' (desired state) and level of 'preparation' (actual state). Interestingly only 2 of the top five attributes (ranked by gap as viewed by the graduates) rated in the top 5 for importance as viewed by academic staff, namely 'sense of accountability' and 'interpersonal skills'. Furthermore only the attributes 'advocate and influence skills' and 'sense of accountability' featured in the top 5 on importance as viewed by the graduates themselves.

These findings conclude the following 4 attributes require attention from tertiary institutions. These show high gaps between preparation and importance based on the graduates' views. They are also high on the importance list as viewed by academic staff and by graduates in the workplace. Added to this is the attribute of 'communication skills' which was inside the top 5 on importance, and was just outside the top 5 on gap ranking (between importance and preparation received).

1. A sense of accountability for actions
2. Interpersonal skills
3. Skills to advocate and influence
4. Communication skills

The above findings from the key stakeholder groups confirm our hypothesis that there is a need for a broadening of engineering education. There is agreement between the surveyed groups that some of the attributes, which are high on importance also feature high on the gap-ranking list. Improvement opportunities should not stop at these 4 attributes, but also consider those with lesser gaps.

Factors that influence engineering curricula development

The research also sought to identify the key 'factors' that influence engineering curricula development. This could lead to an understanding of why gaps or opportunities appear in engineering education today. The research confirmed the importance of industry involvement, which ranked highly among other traditional factors. In addition, university 'staffing levels' and 'staff motivation' (to accept and implement change) are also key factors that influence engineering curriculum development.

Industry feedback via curriculum success evaluations was thought to also be a key factor. Universities have their internal quality control departments survey undergraduates on course material content and delivery, however, with the possible exception of the IE Aust reviews, this does not appear to cover any significant 'quantitative' feedback post graduation. Quantitative feedback analysis from industry sectors' senior engineering staff, human resources staff, and indeed of the graduates in the workplace (Alumni), appears to be minimal. Varying levels of 'qualitative' analysis is carried out at educational conferences, as evidenced by the published materials.

The research project recommends further qualitative analysis to support the quantitative results of these surveys. This would further assist with understanding the interrelationships of the 'factors', which impact engineering curricula development. It is further recommended that engineering curriculum success evaluations be carried out on a more regular basis with downstream customers of the education process, i.e. the employers / industry groups, and of the graduates in the workplace.

References

Chang, I. F. (1998) Challenges to Engineering Education in the 21st Century, Westchester Graduate Centre Polytechnic University. Published via http:/pride-nt1.poly.edu/GISS/ifay98/CCU51398a.html.

Institution of Engineers Australia (2001) Enhancing Local Industry through the Science, Engineering and Technology Capability of the ACT., A position paper prepared for the Chief Minister and the ACT Science and Technology Council by The Institution of Engineers, Australia, Canberra Division.

Inelmen, E., (2001) In Search of Excellence in Engineering Education: from 1998-2001, Bogazici University, Bebek, Istanbul, 80815 Turkey, published in Global Journal of Engineering Education, Volume 5 No. 1, Australia, 2001.

Johnson, P. AO (Chairman Steering Committee) (1996) IE Aust. Report: Changing the Culture: Engineering Education into the Future, Barton ACT, The Institution of Engineers.

Kasuba, R., Vohra, P. (2000) A compound assessment of an undergraduate engineering program, Northern Illinois University, Dekalb, USA., Presented at 3rd UICEE Annual Conference on Engineering Education, held at the University of Tasmania Feb, 2000. Published in conference proceedings (2000) edited by Prof Zenon J. Pudlowski UICEE, Faculty of Engineering, Monash University, Clayton.

MIT (2000) Alumni Survey: Comparisons of all four MIT classes (1979, 1984, 1989, &1994) via MIT website.

Ramos, F. V., (2000) Educating the Global Engineer, presented at "The International Millennial Conference on Engineering Education (IMCEE 2000)." Held in Manilla, Philippines January 2000. Published in Global Journal of Engineering Education, Volume 4 No. 1, Australia, 2000.

Ruprecht, R., (2000) Curriculum development: The whole and its parts, Published in the European Journal of Engineering Education, Abingdon; Dec 2000.

Taylor, E. and Johnson, S. (2000) A new paradigm for engineering education? An Australian approach, Faculty of Engineering, University of Technology, Sydney.

Trigwell, K., and Yasukawa, K., (1999) Learning in a graduate attributes-based engineering course, University of Technology, Sydney. Paper presented at the HERDSA Annual International Conference, Melbourne- July, 1999.

Zahed, A.H., Wanas, M.W.A., Abulfaraj, W. H. (2000) Assessment and development of engineering curricula: a case study, King Abdulaziz University, Jeddah, Saudi Arabia. Presented at 3rd UICEE Annual Conference on Engineering Education, held at the University of Tasmania Feb, 2000. Published in conference proceedings (2000) edited by Prof Zenon J. Pudlowski UICEE, Monash University, Clayton.