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The Essential Skills and Attributes of an Engineer: A Comparative Study of Academics, Industry Personnel and Engineering Students

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This paper presents the results of a survey administered to academics, industry personnel and students with the objective of eliciting their views on what the essential generic and specialist skills and attributes are for a modern engineer. Statistical analysis of the survey results clearly indicates that engineering curricula need to be revised; universities must make provision for engineering subjects, teaching and learning material which are updated and capable of enhancing the skills and attributes of future engineers to meet the changing global environment. The quality of future engineers depends very much on the quality of engineering education, which is itself dependent upon developments in engineering curricula.

INTRODUCTION

The dynamic world in which engineers operate presents them with new demands and provides new challenges in the diverse, profound and incessant changes which confront mankind as it heads towards the 21st Century. Such change is occurring in technology, its practice and application, in the natural environment and, of course, in society's evolving expectations. In such a rapidly changing environment, there is, as the research presented in this paper suggests, too great a focus on technical competence for engineers and not enough on competence in non-technical skills and attributes such as communication, problem-solving and management skills: engineering graduates now require a far broader range of skills and attributes than the technical capability that was formerly demanded.

In order to prepare engineers to meet these new challenges, engineering training and education must be revised and modernised. Changes to the existing curricula should be based upon an assessment of the capacity of the following to meet the current challenges:

- Teaching methodology
- Teaching courseware
- Learning styles
- Learning materials
- Syllabus/subjects

One of the most difficult issues facing engineering educators is how to overcome the problem of what subjects to omit or include within the basic four year engineering degree. Whatever the outcome, the degree programme must be developed to provide engineers with a balanced education in the technical and non-technical disciplines of engineering; exposing engineers to non-technical study areas will broaden their skills and knowledge and increase their job prospects by better meeting industry's requirements.

BACKGROUND

What is engineering?

Engineering is a profession directed towards the application and advancement of skills based upon a body of distinctive knowledge in *mathematics, science* and *technology*, integrated with *busine*ss and *manageme*nt and acquired through education and professional formation in an engineering discipline. Engineering is directed to developing and providing infrastructure, goods and services for industry and the community [1].

From this IEAust definition, engineering can be described as a broad field that embraces knowledge and training in business/management, science, mathematics, social science and (computer) technology. In order for engineers to function effectively in such a multidisciplinary environment, engineering education must have the capacity to instil its graduates with skills and attributes from these diverse areas:

- Social Science
  - communication skills
  - social skills
  - presentation skills
  - interpersonal skills
- Business/Management
  - leadership skills
  - business management skills
  - team-working skills
  - accounting skills
- Computer/Technology
  - computer skills
  - programming skills
  - technical skills
  - design skills
- Mathematics/Science
  - problem solving skills
  - research and development skills
  - analysis/synthesis skills

What is the role of an engineer?

Engineers are involved in the implementation, application, operation, design, development and management of projects and processes, although the type of work that engineers do will vary depending on the chosen field of study:

- Chemical
- Civil
- Electrical
- Materials
- Mechanical
- Industrial, etc

Although the technical demands of each of these engineering disciplines may differ, an engineer, irrespective of specialisation, must be equipped with the soft-engineering (non-technical) skills to confront new challenges in the ever-changing and multidisciplinary field that constitutes engineering in today's global environment.

THE CHANGING ROLE OF ENGINEERS

Engineers in the past were mainly concerned with the technical aspects of engineering, commonly known as hard-engineering. Times, and the roles of engineers, have changed however, and a shift in the paradigm of engineering is becoming more appropriate in today's environment. Although the shift involves a movement towards soft-engineering, the technical aspect of engineering is no less relevant, and technical skills formation remains at the core of engineering. What has changed are the dimensions of the core: equally important now is the inclusion of non-technical subjects as most engineers will be working in a multidisciplinary environment [2][3].

The recent review of engineering education indicated that there are a variety of roles for professional engineers which need to be reflected in engineering curricula; these roles include:

- Engineering managers, who *speak all languages*; leaders in business, industry, society.
- The technically brilliant: researchers, technological innovators, specialists in particular fields.
- Systems engineers: experts in major system specification and design and the integration of a variety of engineering and non-engineering specialties.
- Generalist engineers with a broad technical base and the ability to work across specialist boundaries.

SKILLS AND ATTRIBUTES REQUIRED FOR ENGINEERS TO MEET CHANGES IN THE ENGINEERING PROFESSION

A question that frequently occurs to engineering students is *what are engineering employers looking for when employing engineers?* Responses from industry to this question in an earlier survey included the following unrealistic view:

> *We require an engineering graduate with an equivalent of a person with 10 years experience.*

And the following broad, though realistic view:

> *We require a person with motivation and leadership skills, who is creative, a good team member, risk taking and decisive.*

The survey was later expanded to include academics and students' views to determine what the essential qualities and attributes of engineers are in this changing environment. From the results of the survey it is possible to determine what is needed in the future design of engineering curricula to produce a modern engineer.

With the following fundamental points in mind:

- the level of acquired knowledge of an engineer;
- the necessary skills of an engineer;
- the job requirements of an engineer;
- personal and professional attributes of an engineer;
- attitude of an engineer;

a survey questionnaire was developed to include seven generic skills and attributes, and several sub-groups (specialist skills) within each generic group, as proposed by Pudlowski and Darvall, from which respondents could make a selection [4].

POPULATION DATA

Table 1 provides a summary of the population sample, including the number of surveys distributed, the number of returns, and the number of returns as a percentage. The research results and conclusions in this paper are based on this sample population.

Table 1: The population sample.

	Number of surveys distributed	Number of returns	Percentage %
Academics	172	58	33
Industry	707	81	11
Students	100	47	47

RESULTS AND FINDINGS

Q.1 What do you consider to be the essential skills and attributes of an engineer?

Figure 1 presents the respondents' perceptions of the relevant generic qualities and attributes necessary for the development of a professional engineer. There were seven generic skills and attributes listed in the survey:

- Technical knowledge and skills: practical ability eg use of modern technology.
- Intellectual skills: ability to learn and understand new information.
- Attitudes: behaviour, thoughts and actions.
- Standards of engineering practice: awareness and observance of engineering codes of practice and ethics; understanding of the role of an engineer; and general knowledge of the working legislation and regulations.
- Business practices: understanding of economic and financial issues, and ability to work within a business-orientated environment.
- International/national history and culture: understanding of other cultures and customs.
- Proficiency in languages: understanding other languages and familiarity with technical language.

For the seven generic skills and attributes there were sub-groups, specialised skills and attributes, for respondents to select from; Figures 2 to 8 present the results for each skill and attribute within a sub-group. Tables 2 and 3 show the experimental data represented in the figures as a ranking out of 100, where 100 is the most highly valued (see Appendix for Table 3).

Figure 1 shows that all three groups are more or less in agreement as to what generic skills and attributes are required for the creation of a modern engineer, although the relative importance they place on each quality does vary. Industry consider *attitude* to be of most significance (96.9); academics have placed more emphasis on *technical knowledge and skills* (86.3), and the students' view has overlapped with both academics and industry with 75.7 for both *technical knowledge and skills* and *attitudes*. All three groups considered *business practice*, *international/ national history and culture* and *proficiency in languages* to be least relevant.

It is interesting to note the remarkable difference in rankings between industry and the other two groups,

Table 2: Generic skills and attributes.

CORRESPONDING FIGURE	GENERIC SKILLS & ATTRIBUTES	ACADAMICS	INDUSTRY	STUDENTS
Figure 1	Technical knowledge & skills	86.30	92.30	75.70
	Intellectual skills	62.70	89.20	59.50
	Attitudes	70.60	96.90	75.70
	Standards of engineering practice	55.00	89.20	64.90
	Business practices	27.50	66.20	43.20
	International /national history & culture	23.50	43.10	37.80
	Proficiency in foreign languages	9.80	33.90	29.70

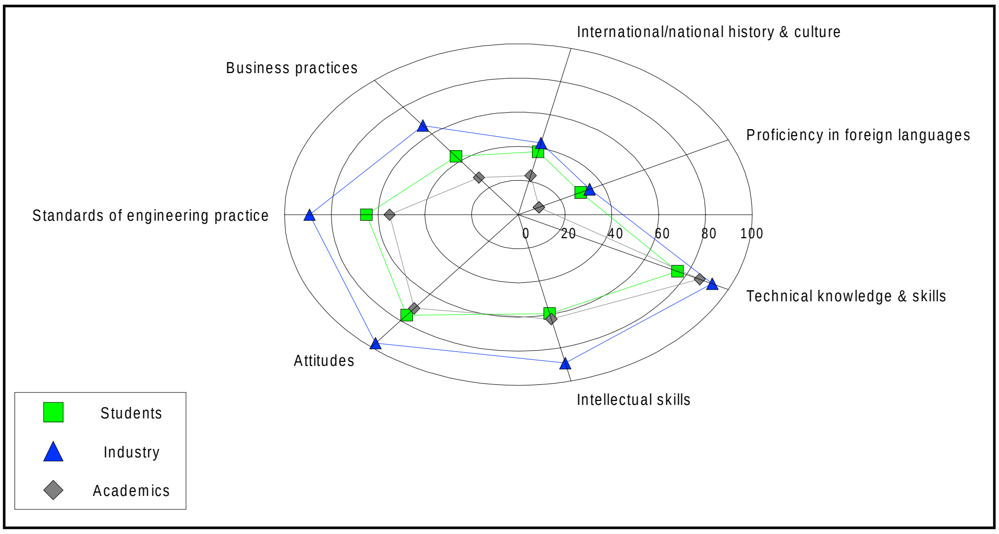

Figure 1: The essential generic skills and attributes as ranked by academics, industry personnel and students.

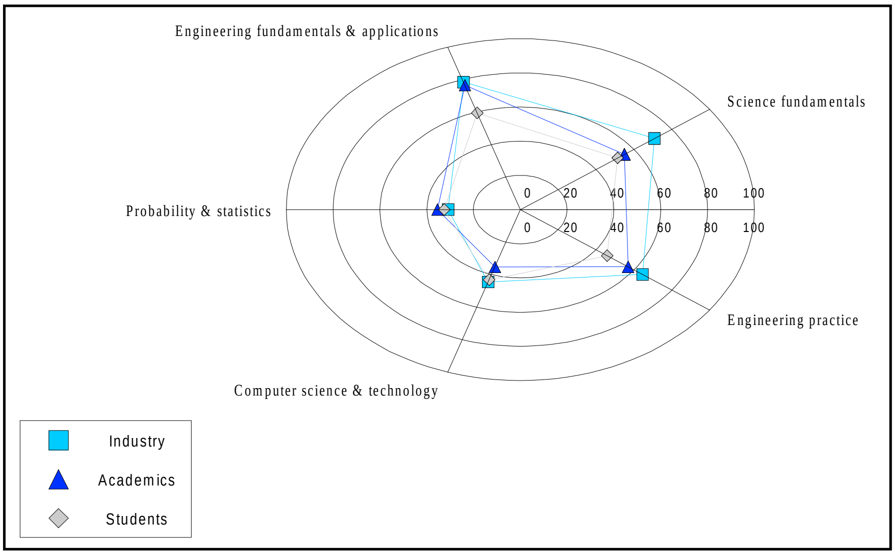

Figure 2: Technical knowledge and skills.

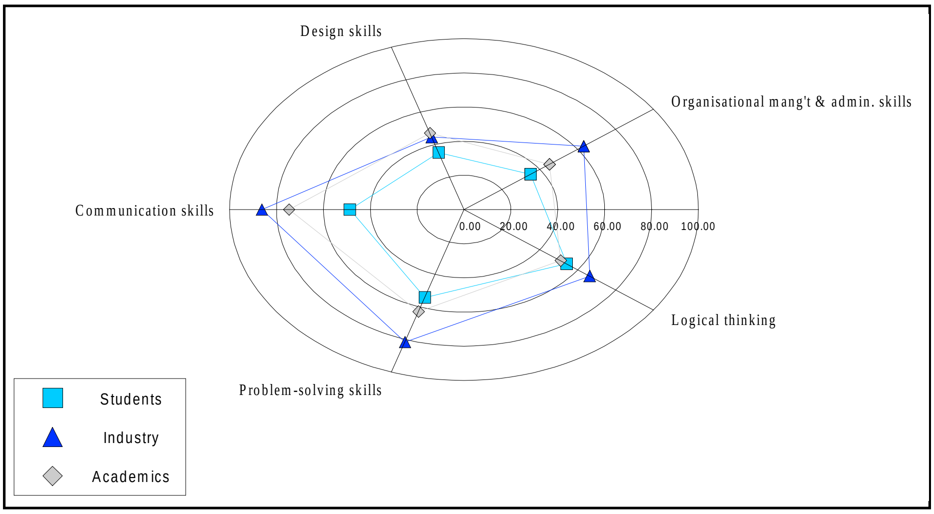

Figure 3: Intellectual skills.

the latter being more inclined to think alike, which is not surprising as they operate in a similar working environment. From these results it is implicit that engineering education is producing a different engineer to that desired by industry, and that engineering education is perhaps failing to meet market demand.

The following is a list of the specialised skills and attributes which were ranked by the groups. These qualities were included in the survey to assist in defining precisely what skills and attributes an engineer is expected to possess.

Technical knowledge and skills (Figure 2) encompasses the following specialist skills and attributes:

- Science fundamentals: knowledge of the basic laws, concepts, theories and principles of science, and understanding of other scientific fields eg chemistry, biology, computer science, earth science, environmental science etc.
- Engineering fundamentals and application: knowledge of the basic laws, concepts, theories and principles of engineering.
- Probability and statistics: the ability to apply mathematical equations and formulas to solve engineering problems and to do statistical analysis.
- Computer science and technology: knowledge and ability to use current software and technology.
- Engineering practice: engineering application, hands-on-skills and hands-on-approach; invention and development of a product; application of technological tools.

Figure 2 shows the ranking of specialist skills and attributes in the generic class *technical knowledge and skills*. There is an almost perfect correlation between the groups, with all three ranking *engineering fundamentals and application*, *science fundamentals* and *engineering practice* of greatest significance. Engineering curricula should therefore provide engineers with a balance of engineering theory and practice and basic science subjects.

Intellectual skills (Figure 3) are defined to include the following:

- Logical thinking: the ability to make logical decisions.
- Problem-solving skills: the ability to resolve issues, problems and tasks.
- Communication skills: the ability to exchange information with other people in the organisation and community.
- Design skills: the ability to sketch, plan and work out designs creatively.
- Organisational, management and administrative skills: the ability to organise effectively; the ability to coordinate, supervise and manage.

Figure 3 indicates that industry and academics share the opinion that *communication skills* and *problem-solving skills* are of particular relevance in the formation of the modern engineer. Students have ranked *logical thinking* and *problem-solving skills* equally high, and have diverged considerably from the other two groups on the issue of communication skills, which may indicate a failure of engineering education to properly instil in students the importance of (and ability to perform) effective communication. From this data it can be concluded that the ideal engineer must be able to think logically, solve problems and communicate effectively.

Attitudes (Figure 4) has been defined in the survey to include:

- Competence: the ability to carry out a task and to do the work.
- Integrity: trust and loyalty to the organisation and colleagues.
- Commitment: dedication to the organisation.
- Tolerance: the ability to withstand and endure pressures and conflict arising in the workplace.
- Flexibility: the ability to adjust to change.
- Commitment to lifelong learning: conditioned to pursue further education.
- Reliability: can the person be relied on? Is the person dependable?
- Conscientiousness: is the person attentive and disciplined in their work?
- Punctuality: the ability to be on time and to meet schedules.
- Approachability: can the person be easily approached? Is the person friendly?

Figure 4 indicates that the top three specialist skills and attributes in this category are *competence*, *commitment* and *integrity*.

Industry places more importance on *competence* and *integrity* than the other two groups, which suggests an industry view that the ideal engineer must be capable of doing the work and committed to the organisation, as well as practising his/her profession with integrity. It is also surprising to note how low academics have ranked *commitment to lifelong learning* when, after all, education is their profession.

Standards of engineering practice (Figure 5) is defined to embrace the following:

- Measurement systems: understanding of standard international measurement systems.

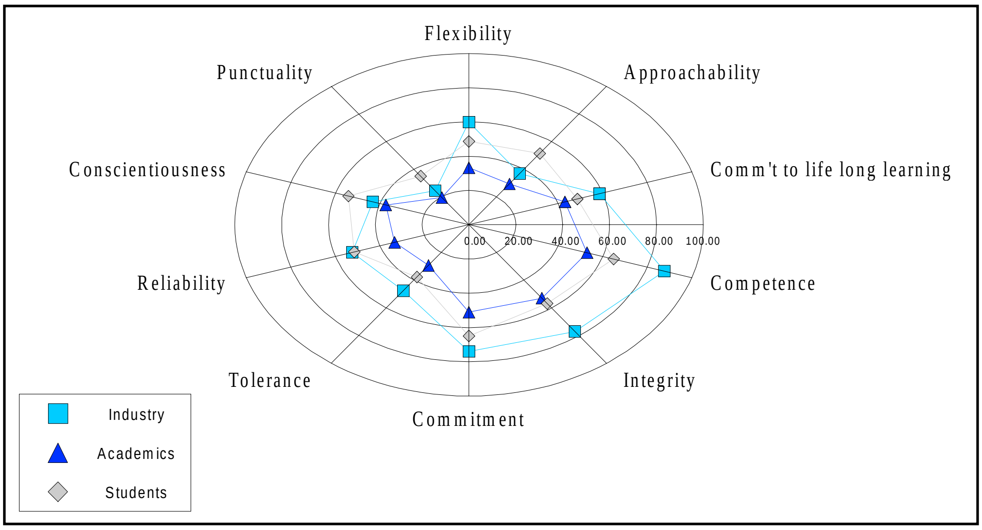

Figure 4: Attitudes.

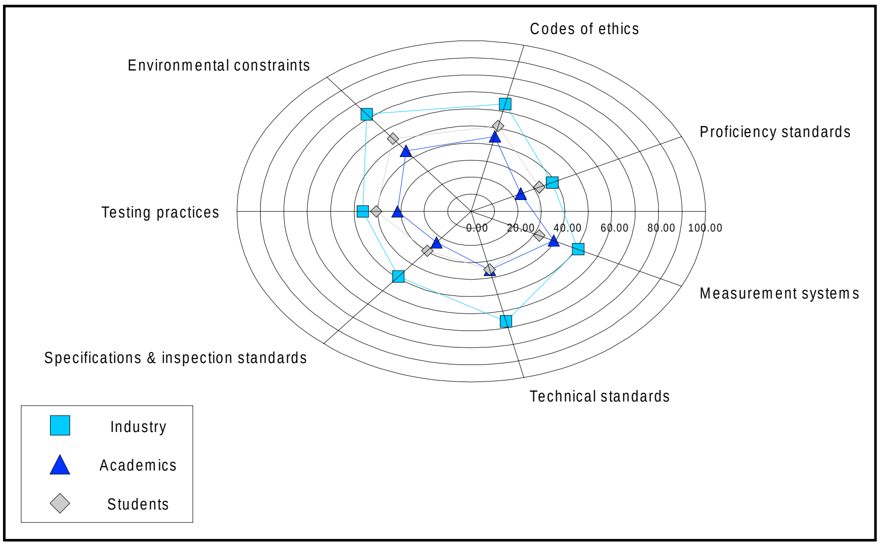

Figure 5: Standards of engineering practice.

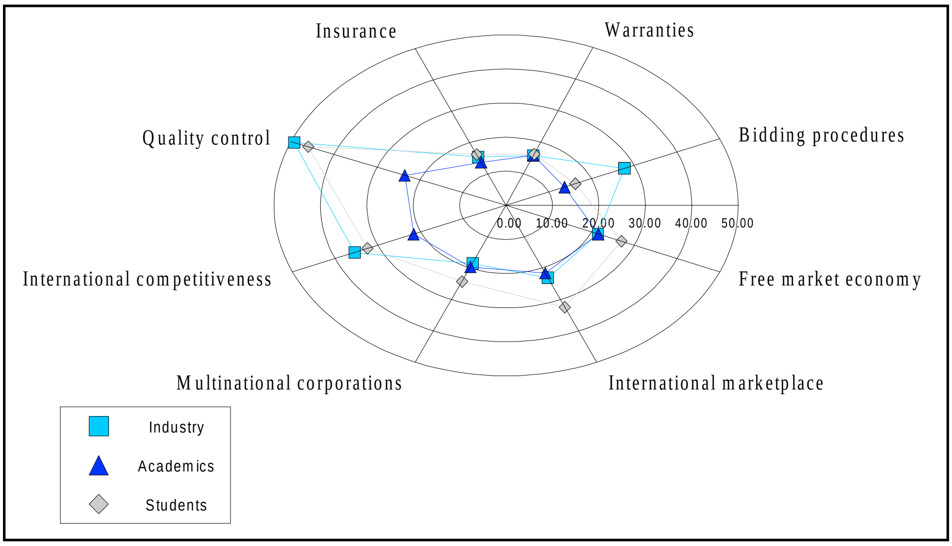

Figure 6: Business practices.

- Technical standards: familiarity with the regulation, codes of practice and standards imposed on technical procedures.
- Specifications and inspection standards: familiarity with technical specifications and standards.
- Testing practices: understanding of common testing procedures in engineering.
- Environmental constraints: awareness of environmental standards and regulations that must be addressed in engineering application and practice.
- Code of ethics: obedience to the standards and codes set by profesisonal bodies; awareness of professional and ethical responsibility to the community.
- Proficiency standards: knowledge of engineering codes/regulations/guidelines.

Figure 5 indicates that all groups consider understanding of *environmental constraints* and *codes of ethics* to be the most important specialist skills and attributes within this category. It can also be observed that *technical standards* and *specifications and inspection standards* are more highly regarded by industry than by academics and students. Familiarity with such standards is perhaps less relevant in a tertiary environment and more useful and commonly applied in the practical industrial environment.

Business practices (Figure 6) consist of the following specialised skills and attributes:

- Free market economy: knowledge of the concepts, principles and operation of the free market economy.
- International marketplace: understanding the global economy as it relates to national markets.
- Multinational corporations: understanding the issues and types of multinational co-operation between individual countries (bilateral co-operation), co-operation between international markets and global co-operation.
- International competitiveness: knowing the issues of competitiveness and how to be competitive in the international arena.
- Quality assurance: familiarity with the auditing, checking, assessment procedures/processes of the company.
- Insurance: understanding issues of one's protection, rights and liability within the international arena.
- Warranties: understanding contractual obligation in terms of conditions and liabilities of products and services.
- Bidding procedures: ability to prepare a business offer/agreement which will be internationally competitive and comprise all contractual elements.

Students and industry in particular have shown more interest in the issue of *quality control* and how to do business and compete in the international arena. Providing relevant business subjects, such as finance, economics and marketing, will prepare engineers to operate and succeed in the global market.

International/national history and culture (Figure 7) includes the following:

- Common history: understanding the history of humankind and the relationships between peoples and nations.
- National history and development: understanding one's own national evolution and history.
- Cultural differences: appreciation and acceptance

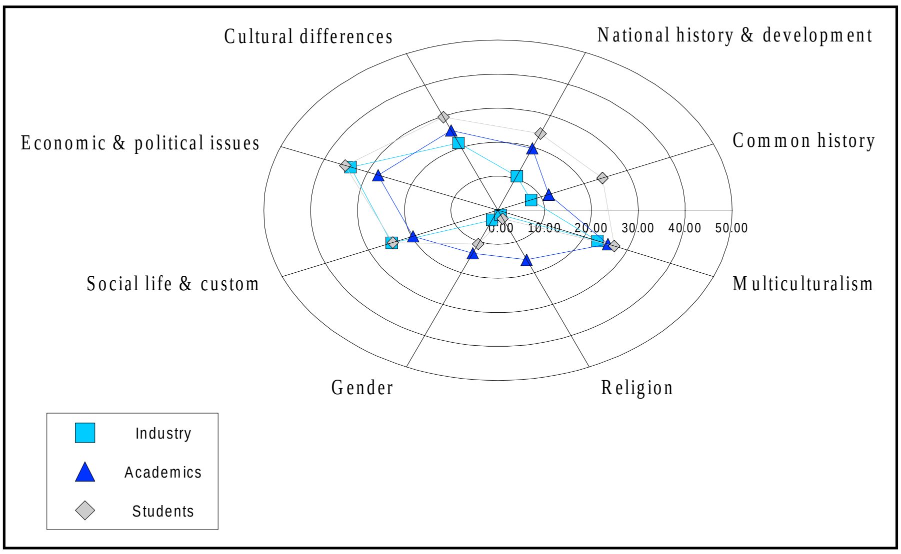

Figure 7: International/national history and culture.

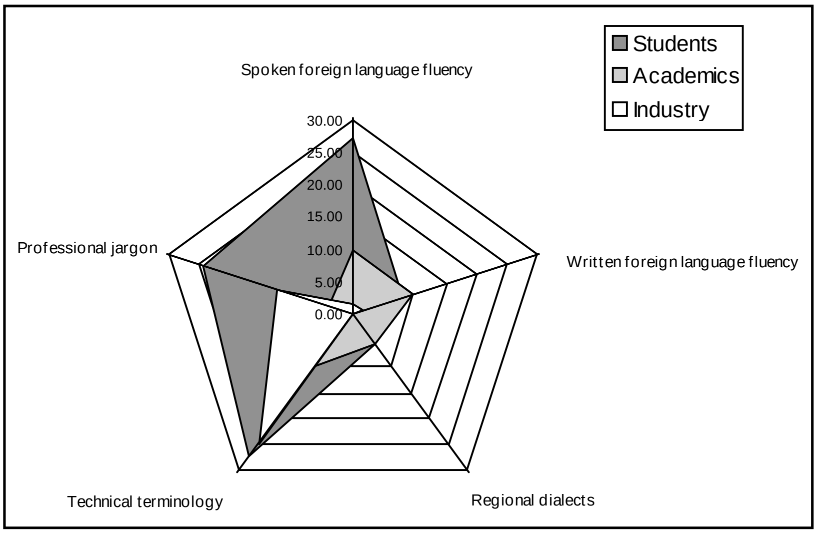

Figure 8: Proficiency in languages.

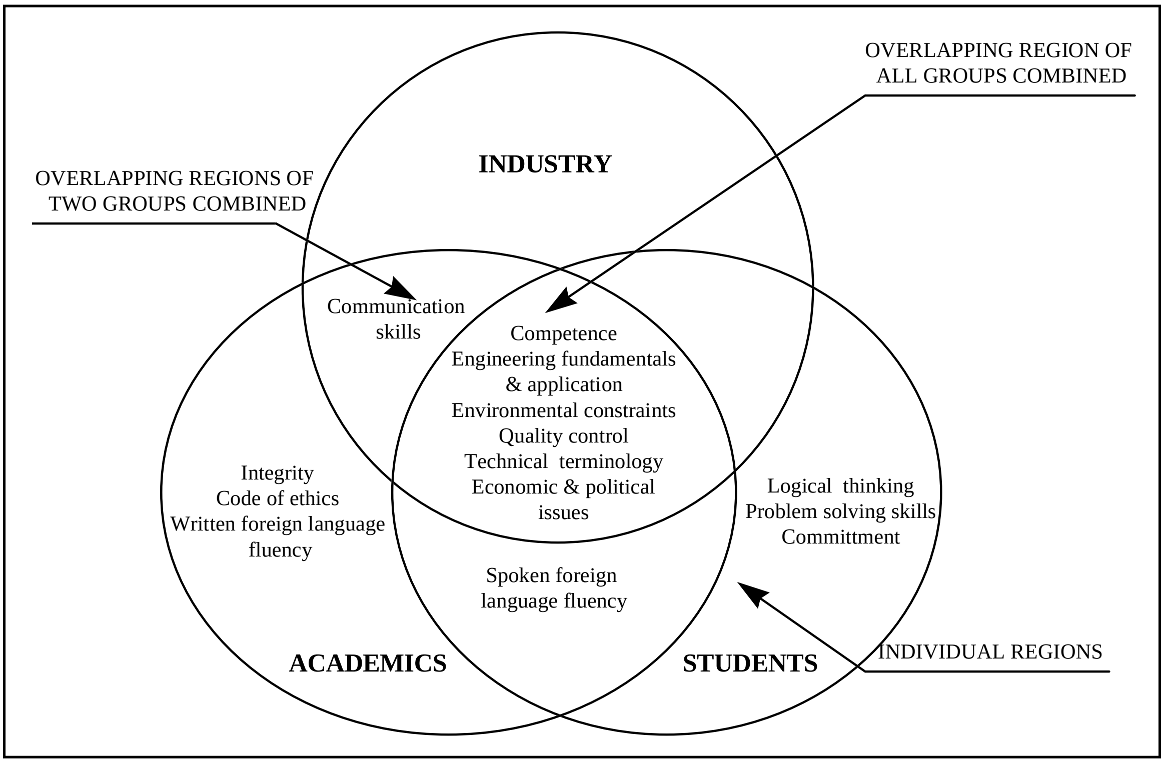

Figure 9: The desirable skills and attributes for an ideal engineer.

of other cultures.

- Economic and political issues: knowledge of national and international economics and political structures and their relationships.
- Social life and customs: understanding the development of society's life and customs.
- Gender: appreciation and promotion of the equality of both sexes.
- Religion: understanding of different religious beliefs and practices.
- Multiculturalism: understanding the diversity of cultures, people and lifestyles.

Proficiency in languages (Figure 8) is defined to embrace:

- Spoken foreign language fluency: ability to speak and understand other languages (bilingual or multilingual skills).
- Written foreign language fluency: ability to read and write in other languages.
- Regional dialects: familiarity with spoken languages peculiar to a region.
- Technical terminology: understanding of technical

terms commonly used in the field.

- Professional jargon: understanding of the informal language commonly used in engineering.

In general the generic groups *international/national history and culture* and *proficiency in languages* were not rated by the respondents to be prerequisites in the development of a modern engineer. From Figure 7 it is clear that all groups stressed the importance of understanding the *economic and political issues* in engineering. In Figure 8 there seems to be an overlap of the opinion given by the groups. Industry have indicated that *technical terminology* is most important. Students have ranked *technical terminology* and also *spoken foreign languages* to be important; academics share the same opinion as students but include *written foreign language skills*.

CONCLUSION

Analysis of the statistics gathered through this survey suggest that the most essential generic skills and attributes of a modern engineer are *technical knowledge and skills* and *attitudes*. The emphasis given to *personal and professional attitudes* by the industrial sector was interesting and indicates that engineers are not only expected to be technically proficient in the field but also to know how to behave and operate within an organisation. Other generic groups such as *intellectual skills* and *standards of engineering practice* were also highly regarded by industry [5].

To further delimit and define the qualities of the ideal engineer the most popular response from each group was taken and combined, as represented by Figure 9. The overlapping region is defined as *essential* ie engineers must possess these skills and attributes. The overlapping region of any two groups is defined as *desirable* ie the skills and attributes listed are not essential but are requested and recommended. Individual regions are defined as *advantageous* ie not essential but beneficial.

It can be said that the ideal engineer must possess sound knowledge of fundamental engineering principles and laws, and must be able to apply the knowledge and convert theory into practice. The engineer must be skilful and practical in the chosen field. The research also indicates that there is growing demand for engineers to understand the impact of their work on the environment and to be able to find environmental solutions to minimise or prevent damage to the environment. The ideal engineer must be able to keep control of the quality of the product, which requires familiarity with auditing and checking procedures, and must understand the common language of engineers and have a broad understanding of economic and political structures and the relationships between different countries.

The desirable skills and attributes for engineers include the ability to communicate effectively, both verbally and in writing, to peers, the employer, client and the community; engineers should also be bilingual.

Advantageous skills and attributes include: loyalty and honesty, an understanding of the engineer's role within society, and the ability to write fluently in another language (academic view); the ability to think logically, to solve problems and to be dedicated/devoted to his/her work (student view).

The ideal engineer is expected to posses a diversity of skills and attributes, with technical competency balanced by non-technical competency. Engineering educators need to acknowledge this diversity in engineering curricula and provide an education which instils these skills and attributes identified by the survey.

In the long term, engineers can only benefit from the possession of these qualities as they will be more competitive in the global market; to succeed in an era of rapid changes and fierce competition engineers must be of the highest quality and must meet the market's requirements.

ACKNOWLEDGMENT

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BIOGRAPHIES

Duyen Q. Nguyen graduated with a Bachelor of Applied Science, majoring in chemistry and environmental management from Deakin University, Australia in 1994. 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, currently as a postgraduate student and part-time project officer. Her special research interests are in environmental engineering education, sustainable development and curriculum development. She is currently pursuing studies for the degree of Master of Engineering Science by research in conjunction with the Department of Mechanical Engineering at Monash University. She has also served on several national and international engineering education conference organising committees. She has already published and presented a number of conference and journal papers in the field of environmental engineering education.

APPENDIX

Table 3: Specialist skills and attributes.

CORRESPONDING FIGURE	SPECIALIST SKILLS & ATTRIBUTES	ACADAMICS	INDUSTRY	STUDENTS
Figure 2	**Technical knowledge & skills**			
	Science fundamentals	55.00	70.80	51.4
	Engineering Fundamentals & applications	76.50	78.50	59.50
	Probability & statistics	35.30	30.80	32.40
	Computer science & technology	35.30	44.60	43.20
	Engineering practice	56.90	64.60	45.90
Figure 3	**Intellectual skills**			
	Logical thinking	51.00	66.20	54.10
	Problem solving skills	62.70	81.50	54.10
	Communication skills	74.50	86.20	48.60
	Design skills	47.10	44.60	35.10
	Organisational, management & administration skills	45.10	63.10	35.10
Figure 4	**Attitudes**			
	Competence	53.00	87.70	64.90
	Integrity	53.00	76.90	56.80
	Commitment	51.00	73.90	64.90
	Tolerance	29.40	47.70	37.80
	Reliability	33.30	52.30	51.40
	Conscientious	37.30	43.10	54.10
	Punctuality	19.60	24.60	35.10
	Flexibility	33.30	60.00	48.60
	Approachability	29.40	36.90	51.40
	Commitment to life long learning	43.10	58.90	48.60
Figure 5	**Standards of engineering practice**			
	Measurement systems	39.20	50.80	32.40
	Technical standards	35.30	66.20	35.10
	Specifications & inspection standards	23.50	49.20	29.70
	Testing practices	31.40	46.20	40.50
	Environmental constraints	45.10	72.30	54.10
	Codes of ethics	45.10	64.60	51.40
	Proficiency standards	23.50	38.50	32.40
Figure 6	**Business practices**			
	Free market economy	21.60	21.50	27.00
	International market place	21.60	23.10	32.40
	Multinational corporations	19.60	18.50	24.30
	International competitiveness	21.60	35.40	32.40
	Quality control	23.50	49.20	45.90
	Insurance	13.70	15.40	16.20
	Warranties	15.80	15.70	16.20
Figure 7	**International/national history & culture**			
	Common history	11.80	7.70	24.30
	National history & development	19.60	10.80	24.30
	Cultural differences	25.50	21.50	29.70
	Economics & political issues	27.50	33.90	35.10
	Social life & customs	19.60	24.60	24.30
	Gender	13.70	3.10	10.80
	Religion	15.80	1.50	2.700
	Multiculturalism	25.50	23.10	27.00
Figure 8	**Proficiency in languages**			
	Spoken foreign language fluency	9.80	1.50	27.00
	Written foreign language fluency	9.80	1.50	8.100
	Regional dialects	5.90	0.00	5.400
	Technical terminology	9.80	24.60	27.00
	Professional jargon	4.00	12.30	24.30