Generic Engineering Competencies Required by Engineers Graduating in Australia

The Competencies of Engineering Graduates (CEG) Project

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Abstract

This thesis identifies the generic engineering competencies required by engineers graduating in Australia, in order to inform future development of instruments to measure the competencies of engineering graduates, and hence help engineering educators to continuously improve engineering education in Australia. The research is based on the viewpoint that part of program evaluation should discover whether graduates have the competencies they will require for their future work.

The theoretical framework is adapted from the Definition and Selection of Competencies Project commissioned by the Organisation for Economic Co-operation and Development. Competencies are understood to consist of knowledge, skills, attitudes and dispositions, and to be manifested in observable actions in context.

This Project's Industry Advisory Committee, consisting of five senior engineers, agreed that employers seek graduates who can become successful established engineers. The research focuses on the competencies required by established engineers, that is, with five to twenty years' experience, to perform their jobs well. This is the first large-scale quantitative research conducted in Australia across all disciplines of engineering, focusing on competencies required by established engineers, rather than recent graduates.

Competencies desirable for engineers were identified from a broad range of literature and refined to 64 items. In a survey, 300 established engineers rated the competencies on importance, and provided details about their work. Outcomes of the survey were confirmed by a second survey of 250 senior engineers.

Large scale quantitative studies for similar purposes had been conducted overseas, but not in Australia. The results are consistent with studies in Europe and the USA, and smaller studies in Australia. Technical, non-technical and attitudinal competencies were perceived to be important. Competencies related to communication, working in diverse teams, self-management, professionalism and creativity / problem-solving were rated as highly important.

Competency factors important to engineers' work were identified statistically using the competency importance ratings. These provide a concise and comprehensive list of the generic engineering competencies that should be developed in an engineering education program in Australia. A focus group was conducted with participants from industry to refine the generic engineering competency model. The generic engineering competency factors are Communication, Teamwork, Self-management,

Professionalism, Ingenuity, Management and Leadership, Engineering Business, Practical Engineering, Entrepreneurship, Professional Responsibilities, and Applying Technical Theory.

The statistically developed eleven-factor competency model offers improvements on the conceptually structured lists of attributes and competencies currently stipulated for engineering education program accreditation. The identified factors are designed to be more distinct than currently stipulated lists. This will make the identified factors more useful, than other lists, for program evaluation purposes.

Current changes to engineering education in Australia, driven by accreditation requirements, are further justified by this research. A recommendation is that entrepreneurship should be considered as an additional competency that Engineers Australia could require to be developed by students in accredited engineering programs.

Analysis of the competency ratings from the two surveys reveals results consistent with gender typing of engineering jobs among the senior male engineers who participated in the second survey. A reference group of people with relevant expertise rated the competencies on stereotypical gender as perceived by professionals in Australia. Stereotypically feminine competencies were more likely than stereotypically masculine competencies to be under-rated by the senior engineers in the second survey, compared with the ratings by the engineers in the first survey. This result has concerning implications. The phenomenon could undermine the development of important stereotypically feminine competencies within engineering education.

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Tribute

When I started this Project I was fortunate to have two grandparents still alive: Bill and Judy Barton. They embraced change, and embodied “do it now”, concern for others, loyalty, positive attitudes, resilience, hard work, and grace. They were leaders, designers, team-formers, and team-players, with technical, spatial, creative, and practical brilliance, and masterful spoken, written, and drawing talents. Using these competencies, Bill and Judy directly improved my life in many ways and contributed to architecture, health, art, sport, aged-care, national security, and education, making Western Australia a better place to live. I am grateful for their examples and hope that this Project will help engineering educators to help many students to enjoy successful lives and make the world an even better place to live.

Statement of Candidate Contribution

This thesis and all papers, on which parts of the thesis are based, are written by the candidate. The candidate has been the corresponding author, and written all revisions and responses to reviewers' comments, for all of the papers on which parts of the thesis are based. The candidate has permission, from co-authors of the papers, to include the work in the thesis.

The project was undertaken by the candidate, with supervision throughout by Winthrop Professor Mark Bush, School of Mechanical Engineering, and for the first three years by Dr Elaine Chapman, Graduate School of Education. The candidate performed the statistical analysis and received advice on this from Mr Kevin Murray, School of Mathematics and Statistics.

A handwritten signature in black ink that reads "Mark Bush". The signature is written in a cursive style with a horizontal line underneath the name.

Supervisor

Mark Bush

A handwritten signature in black ink that reads "Sally Male". The signature is written in a cursive style with a period at the end.

Candidate

Sally Male

Publications Resulting from this Research

This Project has been reported in two published journal papers and one in press, and five refereed conference papers, all written by the PhD candidate. Results have been cited in a first year engineering text book (2010). Details of publications follow.

A review of literature on generic engineering competencies will be published in *Education Research and Perspectives* (Male in press) (Appendix XXXIII).

The original research plan was presented in a refereed conference paper (Male and Chapman 2005). This includes a plan for development of a survey instrument to profile the competencies of engineering graduates using the competency model developed in this research.

Survey 1 (Chapters 5 and 6) and the development of the eleven-factor competency model (Chapter 7) are reported in a manuscript under review (Male *et al.*). Survey 1 results (Chapter 6) have been presented in two refereed conference papers (Male *et al.* 2007, Male *et al.* 2009a).

The analysis of responses to the open questions about perceived competency deficiencies in engineering graduates has been published in the *Australasian Journal of Engineering Education* (Male *et al.* 2010a) (Appendix XX).

A paper, publishing implications for engineering educators (Chapter 10), won the Best Paper Award in the Research Category at the 2010 Australasian Association for Engineering Education Conference (Male *et al.* 2010b).

The analysis of Survey 1 and 2 results to investigate gender typing of engineering jobs among engineers has been published in the *European Journal of Engineering Education* and a refereed conference paper (Male *et al.* 2009c, Male *et al.* 2009b) (Appendix XXXII).

CHAPTER 1. Introduction

This research project (referred to as the CEG Project) identified the generic competencies required by engineers graduating in Australia. It is descriptive research (Mertens, pp. 171-172) and included two surveys and two focus groups.

1.1. Background

The CEG Project identified the generic engineering competencies required by engineers graduating in Australia, in order to inform future development of instruments to measure the competencies of engineering graduates, and hence close the loop in the continuous improvement of engineering education in Australia. The research is based on the view that part of program evaluation should discover whether graduates have the competencies they will require for their future work.

1.1.1. Motivation

1.1.1.1. Reasons to Question the Efficacy of Engineering Education

The research takes the view that it is important to evaluate and improve engineering education so that it is aligned with the needs of engineering graduates. Although universities have additional purposes, there would be few students starting engineering education without an expectation that the program will prepare them for engineering work. Universities have a responsibility to respect the trust students and societies place in them to do this. Three early studies have compared academic performance in engineering courses with effective engineering work and found little or no correlation. One recent qualitative study has also raised concerns.

In the USA, Lee (1986) conducted a study in which 162 supervisors and students from an industry experience placements program rated the performance of the student against

15 competency criteria. These criteria were identified by a literature review and in-depth interviews with engineering managers. Ratings were then factor analysed to determine whether the 15 items clustered into distinct performance groups. Four factors were identified: (i) intellectual, motivational and interpersonal qualities, (ii) written and oral communication abilities, (iii) collection and data analysis skills, and (iv) model-building and instrumentation skills. No significant link between academic and job performance was found, suggesting a possible gap between the criteria used to assess students in academic and industry settings. Instead, Lee revealed a relationship between job performance, and a combination of intellectual, motivational and personal factors.

Newport and Elm's (1997) New Zealand study on qualities of effective engineers surveyed 82 sets of supervisors and engineers with over five years' experience. They found that mental agility, enterprise and interpersonal capabilities formed three main groups of qualities that correlated with effectiveness. "Significantly, academic achievement showed virtually no correlation with engineering effectiveness." (Newport and Elms 1997, p.330).

Similarly, Harvey and Lemon (1994), in the UK, revealed that academic achievement was not a predictor of job success of engineers five to ten years after graduation. Their study included 100 respondents who had obtained a bachelor of engineering degree five to ten years before 1986. Salary was the indicator of success. There was no general relationship between the class of degree obtained and success.

Relatively recent qualitative research has questioned the relevance of engineering education programs. Dahlgren *et al.* (2006), in Sweden, investigated transition from study to work in political science, psychology and mechanical engineering. They found that mechanical engineering education resembled a ritual providing permission to enter the profession and that there was a discontinuity between course content and engineering work.

1.1.1.2. Further Motivation

The CEG Project was initiated by the Advisory Board of the Faculty of Engineering, Computing and Mathematics, at The University of Western Australia (UWA). There have been multiple linked changes to engineering education. Closing the loop in the continuous improvement to engineering education requires evaluation of engineering education programs. Especially due to globalisation, a standardised method to benchmark programs and facilitate mobility of graduates is required. Measurement of competencies of graduates is consistent with competency-based education, which has been adopted for engineering education in Australia. These three developments demand a system to evaluate engineering education programs using measures of the development of competencies.

The prerequisite for development of an instrument to measure competencies of graduates is the identification and selection of the competencies required. Hence, the CEG Project identified the competencies required by engineers graduating in Australia. Following is further explanation of the developments, outlined above, that motivated the Project.

1.1.1.2.1. Competency-Based Education in Australia

A move to competency-based education has been adopted for engineering education in Australia. Competency-based approaches to education stipulate competencies that should be developed by an education program, rather than the traditional stipulations of inputs to the education process such as lists of knowledge, and hours of lectures, tutorials and practical sessions.

Norris (1991) described three types of constructs of competence used in education. The first are the “behaviourist constructs”. These describe behaviours, also called performances, which are actions that can be observed. The behaviourist constructs also include descriptions, called range statements, of the situations in which the actions

should be made, and capabilities indicated by the observed actions. The second constructs described by Norris are “generic constructs” of competence. Rather than referring to behaviours or performances related to specific tasks, these constructs refer to competencies as practices which may be used in more than one task but are common across people who are high performers. A focus on high performing people, rather than specific tasks, leads the generic construct to refer to generic “attributes”. The third constructs described by Norris are “cognitive” constructs. These refer to ability to perform rather than observed performance.

Bowden and Masters (1993) described an evolution of competency-based education and training (CBET) approaches. These started with an approach based on the behaviourist construct, originally introduced in the USA in the 1970s, driven by attempts to align education with industry requirements. CBET was then introduced in the UK in the 1980s and eventually Australia in the 1990s. Bowden and Masters describe the shift from finely specified roles, tasks and behaviours to holistically assessed generic attributes.

In Australia the shift from behaviourist towards the generic and cognitive constructs has continued and been accompanied by an alteration to terminology, with “generic” or “graduate” “attributes” and “capabilities” appearing in the literature, referring to higher education (for example, Bowden *et al.* 2000, Borthwick and Wissler 2003) and specifically to engineering education (Scott and Yates 2002, Bowden 2004).

1.1.1.2.2. Trends in Engineering Education

The context, curriculum and pedagogies of engineering education in Australia have been transformed in recent decades. Changes in both the context in which engineers work in Australia, and the education system, have influenced engineering education (Ferguson 2006b).

Traditional engineering education almost exclusively taught scientific theory and technical skills. Shuman *et al.* (2005) discussed recurring calls, since more than a century ago, for non-technical content such as communication skills and disciplines from the humanities to be taught to engineering students in the USA. As early as 1955, the *Evaluation of Engineering Committee of the American Society for Engineering Education* (ASEE) cited reports from the 1940s which called for 20% of engineering education to reside within the “humanistic-social stem” (Grinter 1955, p.58). This report also cited the 1950-52 ASEE monograph *Improvement of Engineering Teaching*, which called for engineering education to prepare graduates for life-long learning. The 1955 ASEE report reiterated these needs, and highlighted a further need for programs to include “the development of a high level of performance [in communication]” (p.25). The information included in this review was based on contributions from hundreds of individuals from academic institutions and from industry-based engineering companies.

Despite the above calls, changes in other directions occurred following World War II. Prados (1998) and Lang, Cruse, McVey and McMasters (1999) noted shifts in the USA from practical engineering taught by engineers with industry experience until the 1950s to a stronger focus on mathematics and science taught by researchers. Mills (2002, pp. 25-26) commented that engineering education in Australia experienced similar developments and Ferguson (2006a) discussed how, in Australia, creative design was taught until the 1950s when creativity was largely replaced with analytical approaches.

The reviews of engineering education in Australia by Williams (1988b) and a consortium of The Academy of Technological Sciences and Engineering, the Australian Council of Engineering Deans, and The Institution of Engineers, Australia (IEAust) in the following decade (Johnson 1996a) indicated demand for developing the generic competencies of engineers. In both reviews, competency in communication was identified as essential for engineers to describe and justify their ideas. The 1990s review

also pointed to the need for bachelor of engineering programs to foster the engagement of graduates in the broader social, environmental and economic issues of society.

In recent decades, influences on the professional context have included: a movement of engineering work from in-house to consultancies, globalisation, rapid technological change and development of technical specialisations, an increasingly scrutinising society, and increased concern for environmental issues (Beder 1998, Green 2001, Mills 2002, National Academy of Engineering 2004, Becker 2006, Ferguson 2006a, Ravesteijn *et al.* 2006). Consequently, engineering curricula have changed in technical areas and broadened into non-technical areas, as originally called for a century earlier.

Part of the change has been a pedagogical shift in engineering education in recent decades. Traditional lectures, tutorials and laboratories were the main methods of teaching in the 1980s. Since then, problem-based and project-based learning have experienced growing popularity in Australia (Godfrey and Hadgraft 2009). CDIO (conceive-design-implement-operate) (CDIO) and Engineers Without Borders (Engineers Without Borders Australia 2006) are examples of initiatives supporting this. Students now have opportunities to practise communicating and working in teams. Additionally, information technology has facilitated new teaching and learning opportunities.

One of the interrelated drivers for recent change has been the stipulation of outcomes required for program accreditation, consistent with the adoption of competency-based education outlined in the previous section. Since 1997, the accreditation process in Australia has considered both educational inputs and outputs, rather than inputs alone as previously designated.

Engineers Australia (EA) stipulates ten generic attributes of a graduate (EA 2005b, p.3) and Stage 1 Competency Standards (EA 2005a) for program accreditation in Australia. Consequent pedagogical shifts have included the introduction of alternative

approaches such as problem-based and project-based learning, aligned with responses to other drivers for change.

Accreditation documents for engineering programs in many countries stipulate similar lists of program outcomes. The USA-based Accreditation Board for Engineering and Technology (ABET) criteria include program outcomes (ABET 2008, p.2), with outcomes also specified in the UK (Quality Assurance Agency for Higher Education 2006, Engineering Council 2010, Shearman and Seddon 2010). To facilitate quality, mobility and recognition across countries in the European Higher Education Area, the EUR-ACE Accreditation of European Engineering Programmes stipulates six program outcomes (Augusti 2001, Augusti 2006, Augusti 2007, European Network for Accreditation of Engineering Education 2008).

The Washington Accord provides international benchmarking at the graduate level, and EA, which manages the accreditation system in Australia, is a signatory (International Engineering Alliance 2009b). The Washington Accord lists twelve graduate attributes (International Engineering Alliance 2009a) and those stipulated in signatory countries are deemed to be equivalent.

The 2008 review of engineering education in Australia stated that, since the 1996 review, Australian engineering education had now focused on outcomes, used increased innovation such as problem-based and project-based learning, and had a stronger emphasis on communication skills, teamwork, management and sustainability (King 2008). The review was based on statistical data and consultation with students, graduates, employers and academics. Skills shortages and lack of diversity were reported as persistent problems. The CEG Project will assist the following recommendations from the review:

Recommendation 2: refine the definition statements for engineering occupations and graduate qualification standards.

Recommendation 5: engage with industry (p.ii).

1.1.1.2.3. Benchmarking and Globalisation

Further influences on the educational environment in Australia include increased student accountability due to the introduction of university fees. Competition has increased due to factors such as the increasing proportion of universities' incomes being derived from fee-paying students and other non-government sources. This has motivated moves towards the benchmarking of undergraduate degree programs (McKinnon *et al.* 2000, Garlick and Pryor 2004), further highlighting a need for universities to adopt standardised frameworks in evaluating their program outcomes.

As recognised in engineering and noted in the previous two sections, the move towards identifying and measuring outcomes is also motivated by globalisation, which requires cross-national recognition of qualifications in order for graduates to work internationally. This is summarised in the Organisation for Economic Co-operation and Development book, *Quality and Recognition in Higher Education*, which identifies the need for an international framework for recognising both quality in education programs and qualifications. The Executive Summary states:

Rather than trying to achieve convergence of formal input and the characteristics of programmes, it is much more useful to try to enhance comparability at the level of learning outcomes. Descriptions of programmes and qualifications in terms of the learning outcomes and competencies may help to determine their correspondence and, hence, contribute to their recognition across countries (OECD 2004, p.12).

1.1.1.2.4. Evaluation of Teaching and Learning in

Australian Universities

Evaluation of teaching and learning is complicated by the difficulty of selecting and measuring performance indicators. One method previously used to measure the quality of teaching and learning has been students' evaluations. Marsh's (1987) research on

student evaluations of teaching performance led to the Students' Evaluation of Education Quality (SEEQ). He noted extensive earlier literature on students' evaluations. Similarly, the Course Experience Questionnaire (CEQ) was developed to assess teaching at universities based on student evaluations (Ramsden 1991). This rates individual programs, rather than individual staff. Kember and Leung (2009) developed a recent example of students' evaluation of teaching and learning at the program level.

Stakeholders' evaluations have been used in engineering faculties in Australia as a response to the program accreditation requirement to demonstrate development of graduate attributes. For example, Bons and McLay (2003) asked academic staff, human resource staff, senior engineering staff, and graduates from RMIT ($n = 98$ across all categories) to evaluate the extent to which their program developed each of 27 generic competencies. These were broadly consistent with the attributes specified by EA, with the additional 17 including subsets of the original ten. Results were presented in terms of "gaps" between the perceived importance and the perceived preparation of graduates for each competency. Of all 27 competencies, communication skills were found to have the largest "gap" between competency importance and graduate preparation.

In a survey by Ashman *et al.* (2008), among other participants, 40 fourth year undergraduate chemical engineering students, and six managers, rated graduate attributes on importance and competence. Mean importance and competence ratings for each sample group were compared. Managers' and undergraduate students' ratings indicated a deficiency in communication, and managers' ratings indicated a slight deficiency in graduates' business skills.

In an international survey of chemical engineers from 63 countries, during their first five years of employment, participants ranked skills and abilities with respect to the quality of their education, and also the relevance to their work (WCEC 2004). If the average rank for work was lower than that for education, the skill or ability was

identified as being in deficit. On average across all 1091 engineers with bachelor degrees, the skill or ability with the highest deficit was a business approach. Quality management methods, project management methods, management skills, effective communication and leadership were found to have relatively high deficits.

In the USA, a comprehensive and rigorous study was conducted at Iowa State University by Brumm *et al.* (2001, 2006). The study is described in Chapter 2. Fourteen dimensions of workplace competencies necessary and sufficient for the successful demonstration of the ABET outcomes were extracted from the results. The resulting standard assessment survey rated the student or graduate on the following question: “When given the opportunity, how often does this individual perform the action?” across 61 key actions.

An alternative to stakeholders’ evaluations is to test students. The Australian Council for Education Research has developed the Graduate Skills Assessment to test university students when they enter and after they leave an undergraduate course (Australian Council for Educational Research 2001, Hambur *et al.* 2002). Commissioned by the Organisation for Economic Development (OECD), the Australian Council for Educational Research is currently assessing the feasibility of developing a test to evaluate engineering education at the bachelor level.

In summary, motivating factors for the measurement of outcomes as a means of program evaluation include the following:

- There has been reason to question the efficacy of engineering education.
- Engineering education programs have transformed in recent decades, and continue to evolve.
- Evaluation of programs is essential for continuous improvement.

- Outcomes based education is now used as the framework for curriculum development, pedagogical evolution, and assessment, and is therefore appropriate for evaluation.
- Globalisation and the need for benchmarking provide further justification for the measurement of outcomes.

The CEG Project was undertaken to assist the evaluation of engineering education programs in Australia using program outcomes.

1.1.1.2.5. Competencies of Graduates as the Measure for Program Evaluation

To evaluate engineering education, it was necessary to identify the required outcomes. Stakeholders of engineering education programs include communities, employers of engineers, students, and program providers. Confirmation that program outcomes are aligned with the generic competencies required by engineers would imply that engineering education programs are aligned with the following stakeholder needs: for students to graduate with aptitude to develop the competencies they will require to work as engineers, for employers to recruit engineering graduates with aptitude to become competent engineers, for communities to benefit from the work of competent engineers, and for universities to benefit from the reputation of their engineering graduates. These are important among the many critical responsibilities that universities must consider.

1.2. Research Questions

The CEG Project addressed the following main questions:

- What are the generic engineering competencies that engineers graduating in Australia require for their work as engineers?
- What are the generic engineering competency *factors* that engineers graduating in Australia require for their work as engineers?

Sub-questions, with motivation described later in the thesis, were:

- Are the engineering program outcomes currently required for accreditation in Australia aligned with the identified generic engineering competencies?
- Are different generic engineering competencies important for jobs with different tasks and work contexts?
- Do engineers gender type engineering jobs?
- Specifically, are there stereotypically feminine competencies that are important to engineering jobs but affected by gender typing among engineers?

1.3. *Significance*

Society relies on competent engineers to design, and manage the construction and maintenance of sustainable technological solutions for people's needs and wants and for economic success. However, Australia has a shortage of engineers (Australian National Engineering Taskforce 2010). Therefore, effective engineering education is critical.

The CEG Project will assist the evaluation and improvement of engineering education in Australia. It has identified the competencies that are required by engineers graduating in Australia for their future work. The competencies are articulated in an empirically developed factor structure, largely confirming the conceptual lists of graduate attributes stipulated by EA for accreditation of Australian engineering education programs. Eleven competency factors were identified that engineers graduating in Australia require for performing their engineering jobs well.

The main implication arising from this research is that confirmation that recent graduates demonstrate these competency factors should form part of the evaluation of Australian engineering programs, and consequently assist continuous improvement of these programs. The factors are suited to this purpose, being more distinct than the lists of generic attributes (EA 2005b) or Stage 1 Competencies (EA 2005a) currently stipulated for program accreditation. The competencies of engineering graduates from a

program could be profiled using workplace supervisors' ratings of graduates' demonstrations of the generic engineering competencies.

The study found a relationship between the importance of competencies and nature of an engineer's work. Awareness of this would be important for the development of an instrument to measure the competencies of engineering graduates using ratings made by workplace supervisors of graduates. Although the competencies will be needed for all engineering jobs, their importance will vary, and any competency might be more reliably measured among graduates in jobs for which that competency is highly important.

By addressing the final two sub-questions, this research revealed the first quantitative results consistent with stereotypical feminine competencies being under-rated among senior male engineers. The research identified stereotypically feminine competencies that were important and were under-rated among the senior male engineers. This could be undermining the development of stereotypically feminine competencies in engineering education programs and has other serious implications discussed in Appendix XXXII.

Results of this research have been used in teaching of first year engineering students at UWA to demonstrate the diverse range of competencies required by engineers, and especially the importance of non-technical competencies. Results have been cited, similarly, in an Australian text book for first year engineering students (Dowling *et al.* 2010).

By helping to improve engineering education in Australia this research will help engineering educators to fulfil their responsibility to give engineering students the best possible opportunity to develop the competencies they will need to be successful engineers. It will consequently help engineers to contribute to providing society's needs and wants and to contribute to Australia's economic success.

1.4. *Originality*

This is the first quantitative study conducted in Australia to identify the competencies perceived to be important by engineers across all disciplines, focusing on established engineers rather than recent graduates.

This research was different from most previous studies because, in the main large-scale survey, it asked engineers to consider their own current jobs only. Many previous studies asked participants to rate items for importance to a group of engineers, for example, engineering graduates. In this study, collation across the jobs of many engineers was performed in the analysis of results. This was designed to avoid error which, in other studies, may have arisen from participants collating their observations, over multiple jobs or extended periods of time, mentally at the time of their participation. Others have now adopted and adapted the method, developed in this study, for other professions (for example, Jackson 2009).

The research developed factors of the generic engineering competencies, required by engineers graduating in Australia. These were developed statistically from competency importance ratings using exploratory factor analysis, rather than purely conceptually as is most usual. The factors were refined iteratively to make them more distinct than other groups of competencies.

The research revealed the first quantitative results consistent with gender typing of engineering jobs among senior male engineers.

1.5. *CEG Project Industry Advisory Committee*

The study had an Industry Advisory Committee consisting of five senior engineers from small and large organizations in oil and gas exploration and production, metals mining and processing, electronic products and solutions, and construction engineering project management. Members were selected from the Faculty Advisory Board which had

initiated the Project. There were originally five members. However, one retired from engineering during the Project.

1.6. Context: Structure of Engineering Education

Programs in Australia

The engineering educational context is similar across Australia. The ten graduate attributes stipulated by EA engineering education accreditation policy encompass basic science, in-depth technical competence, communication, problem-solving, a systems approach, working alone and in teams, leadership and management, responsibilities, sustainability and life-long learning. Although the importance of technical knowledge and skills remains, the majority of the graduate attributes are not purely technical, several even encompassing attitude, and they symbolise a substantial broadening of engineering curricula.

The accreditation criteria encompass the operating environment, the academic program, and quality systems. Accreditation requires demonstration that graduates have developed outcomes, which are broadly specified by EA, and specifically planned by each program provider. Programs are accredited every five years. Of the three levels of engineers: associates, technologists, and professional engineers, this study focused on professional engineers.

Most professional engineering programs in Australia, called “bachelor of engineering programs”, take a minimum of four years’ study. Many universities have a common first year, allowing students to select their discipline after completing their first year of engineering studies. Students generally undertake both coursework and a major project during their final year. Most programs require students to complete a minimum period of industry experience, often completed as paid vacation employment. A small number of programs include an extended industry placement as part of the degree. Increasing percentages of engineering students in Australia have completed joint degrees,

combining engineering with another bachelor degree such as arts, science, commerce or law, over five years or more.

The industrial context in Australia allows engineering graduates to work as engineers largely without restriction. For Queensland projects, engineers must be Registered Engineers of Queensland. Otherwise, there are few broadly applicable legal restrictions such as requirements for registration. Chartered Professional Engineer status can be gained through assessment of documented evidence of experience demonstrating competencies in practice, and an interview. Continued professional development and engineering practice are necessary to maintain this standing. Satisfaction of criteria for Chartered Professional Engineer qualifies an engineer for registration on the National Professional Engineers Register and as a Registered Engineer of Queensland.

1.7. *Theoretical Framework*

1.7.1. Nature of Competencies

To begin, the conceptual framework for competencies, on which the CEG Project is based, is described. The term “generic engineering competencies” is developed in this chapter and used throughout the thesis.

1.7.1.1. The Need for a Clear Framework

Studies to evaluate qualifications and individuals by measurement of educational outcomes and competencies have been inconsistent in their conceptual frameworks and terminology. Norris (1991) describes three types of constructs of competence used in education: behaviourist, generic, and cognitive, as described in section 1.1.1.2.1. This classification of constructs describes formal theoretical constructs. However, among educational practitioners’ understandings there is even greater complexity.

At the higher education level, Billing (2003) reviewed generic graduate skills desirable for employment in different countries and found that the skills appeared to be

transferable across countries but there was not a common use of terminology and categorization. In Australia, Barrie (2006) found that within one university, the concept of generic graduate attributes varied between disciplines and even between individual academics within the same discipline. In the UK, “key skills” were interpreted differently by engineering academics across various universities (Higher Education Academy 2005). These examples demonstrate the lack of consistency in terminology and conceptual interpretation at all levels of generalisation. A clear conceptual understanding of competencies was necessary in order to plan the research method.

1.7.1.2. The Definition and Selection of Competencies Project

The problem of terminology and conceptual understanding of competencies was sufficiently important for the Organisation for Economic Co-operation and Development to commission the Definition and Selection of Competencies (DeSeCo) Project (OECD 2002). The purpose, outlined in the DeSeCo Strategy Paper was:

to provide a theoretical and conceptual basis for defining and selecting key competencies and a solid foundation for the continued development of statistical indicators of individually based competencies in the future. It also aims to establish a reference point for interpreting empirical results in relation to the outcomes of learning and teaching (OECD 2002, p.6).

The framework developed by the DeSeCo Project was selected as the basis for the framework used in the CEG Project because, the DeSeCo Project was interdisciplinary and international and the conceptual framework it developed was practical yet not over-simplifying. The framework was practical in that it indicated the possibility and limitations of observing competencies. It was not over-simplifying, in that it recognised the complex nature of competencies: that they are interrelated, their attainment develops with time, and context is relevant. An important part of the framework, which added to

its suitability for the CEG Project, is that it states that competencies are learnable (Weinert 2001) and teachable (Rychen and Salganik 2003, p.49).

The DeSeCo Project focused on key competencies for a successful life and a well-functioning society (Rychen and Salganik 2003, Rychen and Tiana 2004). The DeSeCo Project considered multiple issues related to competencies from multiple points of view. For example, the Project discussed the influence of the selection of stakeholders on the selection of competencies. Employers, for example, may desire different competencies in a graduate from the competencies a graduate might desire in himself or herself. For example, an employer might seek excellent technical competencies in a graduate and have little concern for whether the graduate understands the social and political dimensions of workplaces and negotiates the necessary experience to move into higher paid roles or build contacts that could lead to future employment elsewhere. While being possibly unnecessary graduate competencies from an employer's perspective, these competencies would be valuable from the graduate's perspective.

Another issue raised by the DeSeCo Project is the influence of the outcomes for which competencies are selected. For example, it is frequently assumed that competencies for a successful outcome are those that lead to economic success for the individual, the employer, or society. Competencies needed in an engineer, for that engineer to contribute to economic success, could be different from competencies required in an engineer in order for the engineer to contribute to the best possible environmental outcomes for example.

Finally, a further issue raised by the DeSeCe Project is that competencies can be possessed by individuals or by an entity that is a combination of multiple individuals (Rychen and Salganik 2003, pp. 50-52, Rychen and Tiana 2004). This draws attention to the diversity of competencies necessary within the engineering profession and in an engineering team, and whether engineering programs should seek to develop graduates

with diverse strengths, or whether there is a need for a diverse range of engineering program providers, each graduating different styles of engineers. A requirement for diverse engineering education programs, that graduate diverse graduates, was identified by the 1996 review of engineering in Australia (Johnson 1996a). The CEG Project focused on the competencies needed by individual engineers and recognised that the competencies required will differ across jobs.

The CEG Project adopted the following from the OECD DeSeCo Project:

A competence is defined as the ability to successfully meet complex demands in a particular context (OECD 2003, p.2).

Competencies are only observable in actual actions taken by individuals in particular situations. External demands, individual capacities or dispositions, and contexts are all part of the complex nature of competencies (OECD 2002, p.9).

The DeSeCo framework describes competencies as:

manifested in actions, behaviours and choices in particular situations or contexts... attributions of competence (i.e., that an individual possesses a certain level of competence) are fundamentally inferences, made on the basis of evidence provided by observations of performance (Rychen and Salganik 2003, p.48).

1.7.1.3. Consistency of DeSeCo Framework with Studies in Engineering Education

The DeSeCo conceptual understanding of competencies is similar to the following understanding of engineering education outcomes, expressed by Besterfield-Sacre *et al.*:

Each of the EC-2000 learning outcomes must reflect the integration of the cognitive and behavioural – the knowing and doing. It is not enough to have “knowledge of contemporary issues”. The individual must be able to demonstrate that this knowledge can be applied as one encounters new

problems and attempts to achieve solutions (Besterfield-Sacre *et al.* 2000, p.101).

The understanding of competencies as including knowledge, skills, attitudes and dispositions and being demonstrated in actions is also evident in a study conducted at Iowa State University (Brumm *et al.* 2006), and in the CDIO Syllabus (Crawley 2001). The Iowa study identified actions that demonstrate competencies. Identified competencies included *Integrity* and *Quality Orientation*, which require personal traits beyond knowledge and skills. The CDIO syllabus, which originated from the ABET outcomes, lists learning objectives and proficiencies. These include attitudinal items such as initiative, willingness to take risks, perseverance, flexibility, and curiosity, which fit the DeSeCo conceptual understanding of competencies. The CDIO engineering education framework, in response to the abstract nature of engineering programs by the 1980s, also positions engineering in real problems, providing the context which is emphasised in the DeSeCo framework.

Adapting the DeSeCo framework was therefore aligned with frameworks assumed by other studies in engineering education.

1.7.1.4. Adaptation of DeSeCo to CEG Project:

Generic Competencies for Engineers

Based on the DeSeCo framework, a conceptual understanding of the nature of competencies of interest to the CEG Project was determined. The concept of competencies being observed as actions in context and in response to demands was adopted in this study and determined that competencies of established engineers would be identified as actions performed by engineers to do their jobs well. The jobs, including tasks and context, were considered to be the demands.

1.7.1.4.1. *Ideal Definition of Generic*

Engineering Competencies

Adapting the DeSeCo framework to engineering, the following definition was considered to be ideal but not necessarily pragmatic:

Definition 1: “Generic engineering competencies” are competencies that are important across all areas of engineering, and facilitate the success of engineers as individuals and their contributions as engineers to a well-functioning society.

Significantly, this definition reduced the broad context of the DeSeCo Project, from competencies for everyone, down to the context of this study, which is about competencies for all established engineers. In this study, generic engineering competencies were identified as actions performed by engineers to do their jobs well. In this study, the demands in the DeSeCo framework became the jobs, including tasks and context.

1.7.1.4.2. *Pragmatic Definition of Generic Engineering*

Competencies

The other demand present in Definition 1, that of contributing to a well-functioning society, is often embedded in an engineer doing his or her job well, but although ideal, was difficult to include in this study. Competencies exist that are required to contribute to a well-functioning society, but not necessarily needed to perform an engineering job well. This study identified competencies required for engineering jobs but it did not necessarily identify all competencies required for an engineer to contribute to society. For applications of the results it may be necessary to add competencies required to contribute to society although not needed specifically for an engineer’s job. These competencies are beyond the scope of the study reported in this thesis, and therefore the

following definition was adopted, being more pragmatic although less comprehensive than Definition 1:

Definition 2: “Generic engineering competencies” are competencies that are important across all areas of engineering, and facilitate the success of engineers as individuals doing their jobs well.

The use of Definition 2 rather than Definition 1 had the significant impact on this study, of scoping the CEG Project to consider competencies required by engineers to perform their work. Engineering education has broader responsibilities than to prepare students for employment, and universities have broader responsibilities than to educate students. Definition 1 recognises that engineering education has two main obligations: first to prepare graduates with the competencies, including life-long learning competencies, to work as engineers and possibly as engineering researchers or teachers, and second to prepare graduates to contribute to a well-functioning society. The preparation of graduates to contribute to a well-functioning society is important but its study requires a different research method from that employed in the CEG Project.

Definition 2 draws attention to a second question about the scope of the CEG Project. Which kinds of jobs should engineering programs prepare graduates to do well? This question has two parts.

First, non-engineering organizations, such as financial organizations, recruit engineering graduates. As discussed in Chapter 5, engineering graduates performing a broad range of jobs were invited to participate in a survey undertaken as part of the CEG Project. However, people working in non-engineering roles in non-engineering organizations did not participate. It remains to debate whether engineering programs should be designed to accommodate the needs of employers such as financial organizations, and the engineering graduate competencies valued by such organizations remain a topic for future study.

A second part of the above question, about the kinds of jobs for which engineering graduates should be prepared, arises because jobs are always changing and, as raised by Barnett (2004), graduates need to be prepared for the unknown. There is an opportunity beyond the scope of this study for further research into the nature of the future for which engineers should be prepared.

Definition 2 positions this study with respect to other studies on competencies or “generic” competencies. This study is about “generic engineering competencies” which are the competencies that are needed by most engineers to perform their jobs well. In its focus on a single profession, the topic is more specific than more frequently studied topics such as “key” competencies for everyone, and generic graduate attributes for all university graduates. In the inclusion of technical and non-technical competencies, the topic is broader than some conceptualisations of “generic”. The study of generic engineering competencies suits the purpose of the overarching CEG Project which will assist the ongoing development of engineering education programs.

1.7.2. Implications in the Teaching and Learning

Context

The purpose of the overarching study is to inform ongoing development of university engineering education programs and Definition 2 implies an understanding of generic engineering competencies in the teaching and learning context. Research by Barrie (2004, 2006) on conceptual understanding of generic graduate attributes has found that they are linked to assumptions about the position of responsibility for teaching generic graduates attributes: whether generic graduate attributes are developed before, with, or separately although simultaneously, with disciplinary education. Barrie’s framework of conceptual understandings of generic graduate attributes helps position the conceptual understanding of generic engineering competencies understood by the current study.

Barrie interviewed 15 academics in an Australian university to discover how they conceptualised generic graduate attributes in the teaching and learning context. He found differences even within engineering and he identified four levels of conceptual understanding held by academics to understand graduate attributes. Level 1 assumes generic graduate attributes are basic attributes students should have when they enter university and that the university experience should add to these. The higher levels assume increasing complexity in the attributes and the way generic attributes interact with discipline-specific knowledge and skills, and the consequent positioning of responsibility for developing generic graduate attributes at the university. The fourth level sees generic graduate attributes as interrelated with discipline-specific attributes, providing a framework shaping discipline-specific attributes and consequently developed together with these attributes at university.

The CEG Project is about competencies for engineers, rather than generic graduate attributes which are the subject of Barrie's work. In the CEG Project generic engineering competencies are seen as even more complex than Barrie's Level 4 conceptualisation of graduate attributes. In Barrie's Level 4 conceptualisation, generic graduate attributes provide a framework for discipline-specific skills and knowledge. The CEG Project's framework sees generic engineering competencies as including knowledge, skills, attitudes, and dispositions. These are an interrelated combination of both generic graduate competencies and engineering-specific competencies, in which both the generic graduate competencies provide a framework for the engineering-specific competencies and vice versa.

This is consistent with the framework developed by the *Educating Engineers for the 21st Century* study, which conceptualised the "defining [or discipline-specific] and enabling [or generic graduate] skills" as central to the "core competencies" of the engineering graduate of the future, and the combination of these as identifying

engineering graduates and the three identifying roles of engineers as “technical experts”, “integrators” and “change agents” (Spinks *et al.* 2006, p.5).

The implication for the teaching and learning context is that the engineering-specific competencies and the generic graduate competencies support each other and are therefore likely to develop together into the generic engineering competencies.

This concept of generic engineering competencies being interrelated, so that they are not simply technical and discipline-specific, or non-technical and generic, but instead they are all generic engineering competencies, is supported by Faulkner’s studies of engineering practice. Faulkner has found that the tendency for engineers to classify the work of engineers into technical work, which is seen as the real engineering work, and non-technical work, which is not seen as engineering, is both flawed and harmful to the profession (Faulkner 2007). The concept of “generic engineering competencies” avoids this tendency.

1.7.3. Summary of Theoretical Framework

The framework used in the CEG Project assumed Definition 2, above, for generic engineering competencies, and is adapted from the OECD DeSeCo framework.

Similarities with frameworks implied in other engineering education studies exist.

Definition 2 scopes the study to include technical and non-technical competencies needed by all engineers to do their jobs well. This suits the purpose of the overarching project, which will inform ongoing development of engineering education programs.

Adapting concepts from the OECD DeSeCo Project, competencies are assumed to be observed as actions performed by engineers to do their jobs well. A significant feature of the concept of competence from the DeSeCo Project is that competence, demonstrated as performance in response to a demand, namely an engineer’s job including the work context, is a combination of not just skills and knowledge, but also dispositions.

Terms such as “skills”, “capabilities” and “attributes”, are used in this thesis when referring to other studies, because slightly different meanings were intended in the other studies. This study takes the view that “graduate attributes” are directly linked to competencies of graduates; possession of a graduate attribute indicates achievement of a competency.

1.8. Methodology

The methodology assumed the theoretical framework described in the previous section. This framework determined the types of competencies identified, the people whose opinions were collected, the additional information collected about participants and their work, and the wording of questions. With the theoretical framework foremost, techniques previously used in related fields were adapted for this Project.

1.8.1. Established Methods of Identifying and Selecting Work-Related Competencies

Initially, three established approaches to identifying and selecting work-related competencies are considered. These are from the fields of psychology and human resource management. Techniques from these established approaches were selected to suit the theoretical framework and features of the CEG Project.

1.8.1.1. “People Centred” Approaches: Competency Modelling and Variations

Competency modelling techniques from the human resource management field generally select superior performers or examples of high level performance and discover the competencies common across these successful cases (Spencer and Spencer 1993, McClelland 1998). Competency modelling focuses on people or behaviours rather than jobs. Competency modelling is based on the generic construct of

competence, as described by Norris and introduced in section 1.1.1.2.1. A significant example of competency modelling used to identify required competencies of a profession in Australia, was performed by Birkett (1993). Birkett identified and defined competencies and attributes required by accountants in Australia and New Zealand. Among other phases, Birkett wrote to accountants asking them to describe critical events. This was similar to behaviour event interviews (Spencer and Spencer 1993). A closely related technique is the critical incident technique, a prescriptive quantitative technique to study behaviours that are effective or ineffective in critical incidents (Flanagan 1954, Anderson and Wilson 1997).

Studies to identify competencies required by engineers will be discussed in Chapter 2. However, examples with similarities to the methods introduced are noted here. Scott and Yates (2002), and Turley (1992) used forms of competency modelling. Scott and Yates interviewed high-performing engineering graduates to develop a survey. Turley interviewed software engineers who had been identified as high performers and asked them about critical incidents.

The Iowa study is another example of a people-centred approach. It identified competencies and key actions that indicate successful demonstration of required program outcomes (Brumm *et al.* 2001, Brumm *et al.* 2006). Stakeholders were asked to provide examples that demonstrated the required program outcomes. Participants in Brumm *et al.*'s study effectively nominated high performers when describing successful demonstrations of outcomes.

1.8.1.2. “Job Centred Approaches”: Job Analysis and Variations

The second type of approach to identifying work-related competencies is to focus on the job rather than people performing the job. These techniques were used in human resource management before competency modelling. These approaches include

task-centred approaches and job analysis, which involves describing a job in detail. The theoretical framework is the behaviourist construct identified by Norris and introduced in section 1.1.1.2.1 of this thesis. For each competency, elements of behaviour are listed and a range statement is specified to nominate the situations in which the competency is applicable.

Job and task-centred methods are generally suitable in situations with a limited variety of jobs (McCormick 1979, Schippmann 1999, Schippmann *et al.* 2000) because the job is analysed in fine detail. Descriptions of jobs can include the tools used, the size of teams, level of supervision/autonomy, level of job security and the consequences of error. Competencies are determined by considering tasks and work context, usually by asking job incumbents. Job analysis approaches also recommend the use of subject matter experts' opinions to validate outcomes obtained from opinions of job incumbents. Literature provides advice on tools to determine the tasks and the work context (for example, Rohmert and Landau 1983, Weightman 1994, Fine and Getkate 1995, Fine and Cronshaw 1999).

1.8.1.3. Stakeholder Consultation

A third approach to identifying and selecting competencies is to consult a range of stakeholders on the competencies needed. This approach was used, for example, in the *Review of the Discipline of Engineering* (Johnson 1996b), from which the ten generic attributes of a graduate, stipulated for accreditation in Australia, originated. The review was conducted by six task forces each considering the concerns of a different category of stakeholders in engineering education.

Most previous studies to identify and select the competencies required by engineers have used variations on the first and/or third of the above approaches. These are discussed in greater detail in Chapter 2.

1.8.2. Suitability of the Established Approaches for the Theoretical Framework of the CEG Project

The first approach above, competency modelling, by focusing on the people rather than a job, is more likely to identify competencies of the broad range suggested by the theoretical framework used by the CEG Project. As described earlier, the theoretical framework, adapted from the DeSeCo framework, assumes competencies encompass all of the individual characteristics required for a person to respond to a specific demand in a specific context, or more specifically, for an engineer to perform his or her job well. Competency modelling identifies knowledge, skills, attributes and other characteristics, and its focus on behaviours of people rather than jobs, allows for the identification of competencies of the nature understood by the theoretical framework of the CEG Project. Therefore, competency modelling is consistent with the theoretical framework on which the CEG Project is based.

The second approach above, a job-centred approach, also allows for conceptualisation of competencies as including all of the characteristics necessary to perform a job well, including knowledge, skills, attributes and other features. However, due to focusing on tasks and work context, job-centred methods might not identify all attitudinal items. A feature of job analysis that fits the theoretical framework for the CEG Project well is the concept of necessary competencies being determined not only by the tasks required by the job, but also the work context, or not only the “Work Activity Domain”, but also the “Work Context Domain” (Schippmann 1999, pp. 18-19). Work context, as defined for job analysis, can include dimensions such as job security, collegiality and opportunities for development. This is consistent with the DeSeCo Project’s emphasis on the significance of context to the importance of competencies.

The third approach has the benefits and disadvantages of being flexible. The conceptual understanding of competencies can be accommodated. Without prescriptive methods, extra care would be required to maximise reliability and validity of results.

An additional consideration is the past use of methodologies for identification of competencies in the engineering education context in Australia. Ferguson (2001, Ch.4, 2006a) summarised the developments leading to the Engineers Australia *National Generic Competency Standards*. Ferguson wrote that Competency-Based Education and Training (CBET) was applied to engineering education in the USA in the 1970s but suffered from its dependence on job function analysis, a version of job analysis. A revised version of CBET, considering key responsibilities rather than long lists of specific tasks, was introduced in the UK in the 1980s, and later in Australia. This is consistent with the trends in education in Australia identified in section 1.1.1.2.1. The approach linked competencies to behaviour or performance, rather than tasks. The Engineers Australia *National Generic Competency Standards for Professional Engineers* are consistent with this revised style of CBET. The implication from this is that caution would be required to adhere to the chosen conceptual framework for understanding competencies if a technique from job analysis was used.

1.8.3. The Selected Methodology for the CEG Project

The CEG Project is significantly different from most past applications of job analysis and competency modelling. Job analysis and competency modelling have generally been used for purposes where both the variety of jobs, and the variety of work contexts, are narrower than across the profession of engineering. Spencer and Spencer (1993, p.99) acknowledge that behaviour event interviews, which are one possible form of data collection for competency modelling, are too time consuming to be used to analyse a large number of jobs. They suggest surveys as more practical, yet limited by their inability to identify previously unrecognised competencies. The level of detail

originally sought by job analysis techniques would be unwieldy to consider across the broad range of work performed by engineers, and much of the specific detail is more relevant to manual jobs than to professional engineering.

The identification of superior workers, as required to use competency modelling techniques, is not practical when a range of jobs as broad as those performed by professional engineers is considered. Therefore, the approach for the CEG Project was selected to suit the large variety of jobs across the engineering profession. It identified competencies more likely to be found using competency modelling, by asking participants to rate for importance generic competencies encompassing knowledge, skills and personal qualities such as attitudes and dispositions. It adapted techniques from job analysis, collecting data on the tasks and work context to provide contextual information to allow an analysis of whether the nature of the job or characteristics of the participant contributed to variation in competency ratings.

Given the existing literature on competencies of engineering graduates discussed in Chapters 2 and 3, the CEG Project was able to build on findings and results from other studies. Had there been no such base it might have been necessary to employ a qualitative method to explore engineering work and discover and describe competencies that might be important to engineers. Instead, competencies were identified from previous studies, developed into a list, and confirmed as important using two surveys.

1.8.3.1. Survey 1 of Engineers (Job-Incumbents)...

Survey 1 of the CEG Project used a “practice analysis questionnaire” (Raymond 2005) amounting to a simple form of job analysis including only a task inventory and competency inventory and questions on work context. Established engineers were considered the job incumbents.

The theoretical framework emphasises the significance of the context. Therefore, Survey 1 collected data on participants' work contexts and the tasks they performed, as for jobs analysis, and ratings of competencies for importance to doing their jobs well. The DeSeCo report recommended that competencies be considered in clusters called "constellations" (OECD 2002, p.14), or weighted collections of competencies that may be mapped to particular goals. Therefore, it was important for the CEG Project to discover whether different constellations of engineering competencies are relevant in different types of employment.

1.8.3.2. ...Complemented by Survey 2 of Senior Engineers

A feature of job analysis that is inferior to competency modelling is that no attempt is made to select superior performance. Many researchers have discussed the errors in job analysis data. Sanchez *et al.* (1997) found that job incumbents' job analysis ratings are less consistent with ratings made by non-incumbents if the job is complex and if the job incumbents are more satisfied with their jobs. Sanchez *et al.* recommended that ratings made by job incumbents and non-incumbents should be used to complement each other. These circumstances apply to the CEG Project. Therefore, a survey of senior engineers, Survey 2, was implemented to complement the survey of the job incumbent established engineers.

Sanchez and Levine (2000) and Morgenson and Campion (2000) note it should not be assumed that differences between opinions are due to unwanted error made by either the job incumbents or the non-incumbents. They recommend that it is more important correct inferences are made from the data, than the data are "true" values. The CEG Project did not use the specific structured form of job analysis discussed by these authors. However, the implications applied and hence provided further argument, in addition to the wide variation in jobs performed by engineers and the lack of

identification of high performers as demanded by competency modelling, to survey both established engineers (job incumbents) and senior engineers (non-incumbents).

1.8.3.3. Survey 1 Participants were Established

Engineers rather than Recent Graduates

Norris (1991) notes that a problem arises if task and hence competency definitions are too specific, because transferability to different tasks and situations cannot be assumed. Elkin (1990) introduced two concepts which resolve some of the confusion related to competencies. The first concept uses the terms “micro-competencies” and “macro-competencies” (Elkin 1990, p.23). Micro competencies are related closely to tasks, similar to behaviourist competencies found using job analysis. Macro competencies are underlying qualities of people, or the generic competencies more often found using competency modelling.

Elkin’s second concept explains that the two of these can be used together. Elkin (1990, p.24) describes how a job can require both “initial competencies”, as the minimum competencies, often micro-competencies, and “developmental competencies”, which are often macro-competencies. The initial competencies are required by someone entering a job, and developmental competencies are particularly needed for someone to develop within a job and perhaps into a higher level job. Elkin notes that developmental competencies for one job can become the initial competencies for a higher level job.

The results of Scott and Yates’ approach which identified a list of important capabilities by asking two recent graduates, was influenced by this. The capabilities identified, such as *being able to work with senior staff without being intimidated* (Scott and Yates 2002, p.366), were largely initial competencies rather than developmental competencies.

Members of the CEG Project Industry Advisory Committee agreed that, rather than expecting engineering graduates to be competent immediately, employers generally

seek engineering graduates who have the competencies to develop into useful engineers. Therefore, the study identified the competencies that are perceived to be important by “established engineers” to perform their work.

Therefore, in the CEG Project, to identify macro- rather than micro-competencies, the job incumbents surveyed were “established engineers”, that is, engineers with five to twenty years’ experience, rather than recent graduates.

Engineers were expected to know their work better than anyone else. Teichler (1999, p.300) discussed the concern that some studies have over-emphasised “general” over “specific” skills because managers and human resource professionals, rather than people involved in the detail of work, have been asked about necessary competencies.

1.8.3.4. Source of the Task Inventory in Survey 1

The Engineers Australia *National Generic Competency Standards: Stage 2 for Professional Engineers* (IEAust 1999b) must be demonstrated by engineers seeking chartered status, and signify higher levels of competence than the graduate level. The *Stage 2 Competency Standards* were adapted to become items in a task inventory in the survey of established engineers. Additionally, a panel session with nine people working in engineering research was held to identify task items required by engineers working in research, due to a perceived possible gap in the Stage 2 Competencies.

Further detail about the method for each phase is provided in following chapters.

1.9. Research Plan and Structure of the Thesis

Chapter 2 reviews previous studies to identify and select competencies required by engineers. This is followed by chapters reporting phases of the study.

A broad range of literature was reviewed in order to develop a survey on the work and required competencies of established engineers. From this, competencies were identified and refined into a list suitable for a questionnaire (Chapter 3).

A task inventory for Survey 1 was developed by adapting the Engineers Australia *National Generic Competency Standards: Stage 2 for Professional Engineers* (IEAust 1999b). A panel session was held to identify the tasks performed by engineers working in research and development, in order to complete the task inventory (Chapter 4).

Established engineers were surveyed on their work and required competencies (Survey 1). Senior engineers were surveyed to confirm the outcomes of the survey of established engineers (Survey 2). The method for both surveys is reported in Chapter 5.

Results from both surveys were analysed at the item-level (Chapter 6).

Generic engineering competency factors were identified (Chapter 7) and variation of the importance of these across engineering jobs was studied (Chapter 8).

A focus group was held to refine the descriptions of the competency factors (Chapter 9).

The final chapters discuss main results and findings and their implications (Chapter 10), reflections on the method (Chapter 11), recommendations for further research (Chapter 12), and conclusions (Chapter 13).

CHAPTER 2. Previous Studies

Studies to identify required competencies of engineers have been conducted across North America, Europe, Australia, New Zealand and South Africa. The literature includes documentation for accreditation of engineering education programs, reports of surveys of employers, graduates and engineers, and discussions by engineers and engineering educators. Various methods and theoretical frameworks have been used. A consistent result of such studies is that communication, teamwork, and attitudinal factors are considered to be highly important. Studies are outlined below, beginning with engineering education program accreditation criteria.

2.1. Outcomes Stipulated for Accreditation

In Australia, graduate attributes stipulated by EA for program accreditation originated from the Johnson (1996a) review of engineering education. This review, initiated in 1992, was jointly sponsored by the Australian Council of Engineering Deans, The Institution of Engineers Australia (now EA), and The Australian Academy of Technological Sciences and Engineering. The review was conducted by six task forces with various chairs and methodologies, each considering the concerns of a different category of stakeholders in engineering education. Since then, *National Generic Competency Standards: for Stage 2 and the Advanced Stage Engineer* (IEAust 1999b), and more recently *Stage 1 Competency Standards* (EA 2005a) for the graduate level, have been developed and updated by EA.

As noted in Chapter 1, EA, which manages the accreditation system in Australia, is a signatory to the Washington Accord, which provides international benchmarking at the Stage 1 level across 13 countries (International Engineering Alliance 2009a, International Engineering Alliance 2009b). One factor that has made this international agreement possible is that the signatory organizations in other countries have developed

similar lists of program outcomes. For example, the program outcomes stipulated by ABET, which represents the USA in the Washington Accord, are similar to the EA graduate attributes (ABET 2008).

Outcomes-based engineering education is well established in the UK. The Engineering Council represents the UK in the Washington Accord. The Quality Assurance Agency for Higher Education (QAA), which assures institutions rather than programs, has published a benchmarking statement for engineering (Quality Assurance Agency for Higher Education 2006), based on 2004 standards stipulated by the Engineering Council UK (now known as the Engineering Council), which have since been updated and specify standards for registration of engineers (Engineering Council 2010). Soon after the QAA had published an outcomes benchmarking statement in 2000, the (UK) Engineering Professors' Council also published program output standards containing generic abilities, which were considered to be compatible with the QAA outcomes. One such ability referred to generic skills such as communication and problem-solving, and the remainder were steps in the design process (Maillardet 2004).

The EUR-ACE project, introduced in section 1.1.1.2.2, has finely operationalised six program outcomes for Europe (European Network for Accreditation of Engineering Education 2008).

Outcomes have also been specified for the CDIO (Conceive Design Implement Operate) Syllabus, which is being used at many universities around the world to improve engineering education (Crawley 2001). As noted in section 1.7.1.3 of the Introduction, the CDIO syllabus is consistent with the theoretical framework for the CEG Project, because it includes attitudes and emphasises context. The syllabus was first developed by the Massachusetts Institute of Technology (MIT) and three universities in Sweden (Bankel 2003). The syllabus was developed using focus groups, a review of literature, surveys, workshops and peer reviews. Focus group participants

included academics from MIT and other USA universities, MIT students, and industry leaders. MIT faculty and alumni and senior industry leaders were surveyed. The syllabus is more comprehensive than the ABET outcomes. A main modification made by the Swedish participants was the addition of the need for engineering graduates to communicate in a foreign language. This is consistent with Billing's (2003) international review of higher education graduate attributes which found few differences across countries, except terminology and that a second language had a higher priority in Europe than other countries such as the USA. The CDIO syllabus is long, having fine detail at four levels. This has been designed for curriculum development and assessment. However, it would need to be adapted for program evaluation involving ratings of graduates by workplace supervisors, which is the application for which the CEG Project is designed.

Engineering academics have invested much time in mapping the CDIO syllabus to engineering programs. Popp and Levy have combined the Australian *National Generic Competency Standards for Stage 1 Professional Engineer* together with the CDIO syllabus, creating a detailed syllabus and software for mapping the outcomes of an Australian engineering program (Popp and Levy 2009). Just as Ferguson (2006a) concluded, Popp and Levy found that innovation and entrepreneurship are required in addition to items required for accreditation in Australia. Popp and Levy clarified these in the combined syllabus.

In South Africa, Woollacott (2003) thoroughly reviewed models of engineering work and competency models for engineers, and conceptually, based on the review, developed a *Taxonomy of Engineering Competency*. The taxonomy is consistent with the theoretical framework for the CEG Project, focusing on knowledge, skills, and especially dispositions required for doing engineering work well. With 166 fourth level goal statements, Woollacott's taxonomy is less detailed than the CDIO syllabus, which

possibly makes it more suitable for the purpose of the CEG Project. However, the taxonomy has not been validated empirically.

Woollacott's (2009) comparison of the CDIO syllabus with his taxonomy reveals the significance of methodology. Woollacott found that relevant parts of the CDIO syllabus were substantially equivalent to his taxonomy. The main difference was that advanced dispositions in Woollacott's taxonomy, which he had adapted from Spencer and Spencer's *Generic Competency Model for Technical Professionals* (1993, p.163), were not present in the CDIO syllabus. Having been identified using competency modelling, these were required for superior performance, and not necessarily for performance at effective although not superior levels.

2.2. Four Large-Scale Surveys in Europe and the USA

Four significant studies have surveyed stakeholders to identify the competencies needed by engineers. These are the *SPINE: Successful Practices in International Engineering Education Benchmarking Study* (Bodmer *et al.* 2002) with ten partner universities in Europe and the USA, the *Educating Engineers for the 21st Century* study conducted for the Royal Academy of Engineering in the UK (Spinks *et al.* 2006), a study at Iowa State University (Brumm *et al.* 2006) and one at Illinois State University focusing on non-technical competencies in science, mathematics, engineering and technology (Meier *et al.* 2000).

The SPINE study surveyed 543 academic staff, 1372 engineers with five to ten years' experience since completing a bachelor, master or diploma degree from a participating university, and 143 human resource and line managers (Bodmer *et al.* 2002, pp. 57-61). The Royal Academy study used interviews and focus groups with industry to identify competency items desirable in engineering graduates, and a survey which collected responses from 444 companies (Spinks *et al.* 2006). Both the SPINE and the Royal

Academy studies considered broad-level items and focused on knowledge and skills without explicitly considering attitude, although the Royal Academy study's theoretical framework allowed for attitudes to be encompassed within skills.

In contrast, attitude was important in the Iowa and Illinois studies. As noted in the Introduction, the Iowa study used a form of competency modelling, isolating successful demonstrations. The Iowa study consulted 212 stakeholders including employers, staff, students and international faculty members, who described examples of successful and unsuccessful demonstrations of the ABET outcomes. From these, 14 competencies encompassing attitude were identified and expanded into 61 key actions.

The Illinois study by Meier, Williams and Humphreys (2000), focused on the competency gaps in education of graduates, as perceived by business and industry. The method included repeated literature reviews, content analysis, item generation and interviews, followed by a survey in which 415 managers of employer organizations rated the importance of 54 competencies, including many attitudinal competencies which were found to be highly important. The survey requested evaluation of the importance of competencies and of the technological workers' possession of the competencies itemised. The competencies of individual workers, rather than technological workers in the organization generally, were not rated. Finally focus groups verified and expanded the results.

The Iowa and Illinois studies were more closely aligned with the theoretical framework of the CEG Project, than were the Royal Academy study or the SPINE study. The results of all four of these large-scale studies indicated that non-technical items, especially communication and teamwork, are important to engineering, and the Iowa and Illinois studies indicated that attitudes are also important.

2.3. Other Studies Outside Australia

The National (USA) Academy of Engineering in *The Engineer of 2020* (2004) considered future scenarios, and speculated that engineers will require the following: “strong analytical skills”, “practical ingenuity”, “creativity”, “good communication”, mastery of “the principles of business and management”, leadership in business and also “nonprofit and government sectors”, “high ethical standards and a strong sense of professionalism... recognizing the broader contexts”, “dynamism, agility, resilience, and flexibility”. Furthermore, engineers will be “lifelong learners” (National Academy of Engineering 2004, pp. 54-57). The method was qualitative and began with a three-day workshop.

In the UK, a survey of 53 senior managers involved in training and development of professional engineers in the oil and gas industry rated ten personal skills on importance for their engineers (Connelly and Middleton 1996). The definition of “engineers” did not include managers. Written communication skills, oral communication skills, and team working skills were the highest rated personal skills. Of the nine professional skills, those rated highest were an ability to see engineering in a broader business context and knowledge of the information technology and systems supporting business operations.

Participants also indicated whether any of their engineers would gain from additional training in specific areas. Engineers who qualified in the previous five years most needed oral communication skills, time management and written communication skills. Those who qualified more than five years before the survey was conducted most needed additional training in *teambuilding skills, coaching/development of others, financial skills, information technology and systems, and time management*.

The above study demonstrates Elkin’s concept introduced in section 1.8.3.3 of the Introduction. This section described the decision, in the CEG Project, to survey

established engineers with five to twenty years' experience rather than recent graduates, to select macro developmental competencies rather than micro initial competencies required of graduates.

Another study was conducted in Germany (Fleischmann *et al.* 1998). Engineers from 215 machine engineering factories in Bavaria and Baden-Württemberg were presented with a list of attributes, relevant for design engineers within various categories (for example, design knowledge, information technology skills, measurement and control techniques). Respondents rated the importance of each attribute for work performance. Results indicated that conceptual design skills (for example, 3D imagination) were perceived to be of high priority, while detailing skills (for example, technical drafting) were rated as medium or low priority. This study was pertinent only to a small number of specific engineering roles, namely those within machine engineering factories. This is an example of a study in which the nature of the attributes was narrower than that of the competencies understood by the theoretical framework for the CEG Project.

Other studies have been conducted in specific fields of engineering. In an international survey of chemical engineers from 63 countries, during their first five years' employment, participants ranked skills and abilities with respect to the quality of their education, and also relevance to their work (WCEC 2004). Mason (1998) focused on competencies related to manufacturing. Turley (1992) used competency modelling and interviewed high performing software engineers in one organization, asking them about critical incidents. Competency modelling was also undertaken to identify the competencies of highly regarded systems engineers at NASA (Derro and Williams 2009). Interviews, shadowing and observations identified competencies in five clusters: leadership, communication, problem-solving, systems thinking, attitudes and attributes, and technical acumen.

Related studies with different purposes include two in the USA. One explored the competencies that increased workplace adaptation of engineering graduates (Sutton 2004, Reio and Sutton 2006). The other operationalised the ABET learning outcomes using Bloom's Taxonomy (Besterfield-Sacre *et al.* 2000). An application was the development of an assessment rubric to track development of the ABET outcomes.

2.4. Studies in Australia

Although large-scale studies on the competencies required by engineers have been conducted in the USA and Europe, there was a need for a large-scale survey in the context of Australian engineering programs. Small-sample research conducted in Australia has included the following: a study by Scott and Yates (2002) involving 20 graduates and 10 supervisors; Nguyen's (1998) study on the skills and attributes of engineers as rated by 186 participants including industry members, academics, and students; Ferguson's (2006a) doctoral study with a purposive sample of 16 managers, on the attributes required by Stage 1 (graduate-level) and Stage 2 (chartered level) mechanical engineers in Australia; and a Monash graduate employer survey including 109 engineering-related employers (Nair *et al.* 2009). These studies all encompassed knowledge and skills, and all but the Monash study included attitudes and implied theoretical frameworks similar to that of the CEG Project.

Scott and Yates collected ratings of the importance of 49 professional capabilities. The items were identified from interviews with two successful graduates with between three and five years' experience. As noted in the Introduction, this was similar to competency modelling. Ten workplace supervisors and 20 high-achieving engineering graduates rated the importance of the previously identified professional capabilities. As noted in the Introduction, the graduate-level perspective is evident in the items, for example *being able to work with senior staff without being intimidated* (Scott and Yates 2002, p.366).

Ferguson argued that, in addition to the EA graduate attributes, engineering graduates require the following: *innovation, entrepreneurship, critical thinking, information access and management, time management, language skills, and broad engineering education*. Ferguson found that from 12 groups of 80 attributes, the most important groups of attributes at both Stages 1 and 2 were *Communication, Management, Personal Attributes* and *Problem-solving*. His study applied only to mechanical engineering.

In Nguyen's study, industry participants rated attitudinal skills and attributes as the most important group of generic skills and attributes for engineers. The stage of engineer for which the attributes were rated was not specified. The attributes rated as most important in the Monash survey related to communication, ability to learn, and teamwork.

Trevelyan (2008) has undertaken a qualitative study to describe engineering practice using empirical ethnographic research. He and colleagues have conducted over 100 interviews of engineers and extensive field observations. Trevelyan has identified multiple roles performed by engineers. Coordination of the work of others has been found to be especially important and not recognised elsewhere (Trevelyan and Tilli 2006). Trevelyan and Tilli (2008) have undertaken a longitudinal study of engineering graduates to investigate the work and learning of graduates in their first years of employment. They found that graduates spent 60% of their time interacting with other people.

The goal of the CEG Project was to identify generic competencies that are important across a larger sample of engineers across all disciplines of engineering in a context relevant to engineering education programs in Australia. This is the first large-scale quantitative study conducted in Australia that has encompassed all engineering disciplines and focused on established engineers rather than recent graduates.

Competency factors are identified as a set of competencies that is short enough to be measured in graduates, by using ratings made by workplace supervisors, for program evaluation. Each competency factor is an underlying theme among the generic engineering competencies and is reflected by multiple generic engineering competencies. For example, the Professionalism Factor, is reflected by competencies such as *loyalty*, *honesty* and *commitment*.

CHAPTER 3. Development of a List of Competencies

3.1. *Introduction*

The CEG Project method includes two surveys to select the competencies important to engineers for performing their work well: Survey 1 of established engineers, with five to twenty years' experience, and Survey 2 of senior engineers. Survey 2 was to validate the outcomes of Survey 1.

In accordance with the theoretical framework, competencies consisting of knowledge, skills, attitudes and dispositions, that are manifested as observable actions in response to demands in context, were identified. A sub-question arose from the theoretical framework's expectation that demands and context influence required competencies. In the CEG Project, the demands and context were the engineers' jobs, including tasks and work context. The sub-question was:

Are different competencies important for jobs with different tasks and work contexts?

To address this question, data about tasks and work contexts were also collected in the surveys.

Survey participants rated the competencies. However, first it was necessary to identify competencies, and refine these into a list suitable for inclusion in surveys.

3.2. *Identification of Comprehensive List of Competencies*

Desirable competencies for engineers were identified from a broad range of literature including work on competencies, higher education and engineering education, and

studies such as discussed in the Introduction. These competencies and their sources are presented in Appendix II. The list was sorted into classifications used by Birkett (1993) (Appendix III).

Identified competencies were refined to a list of 64 items for rating in the surveys (section 3.3). Consistent with the theoretical framework, technical, non-technical and attitudinal competencies were included.

All but one of the graduate attributes and items stipulated by ABET, EA, and EUR-ACE were represented in the questionnaire. The EA graduate attribute *in-depth technical competence in at least one engineering discipline*, which is similar to the EUR-ACE Outcome *Knowledge and Understanding* for Second Cycle graduates, was not included in the questionnaire because it was not considered generic. This item was assumed to have various specific manifestations. It was assumed to be important.

Other competencies were included in response to repeated promotion in engineering literature. For example, many engineering programs have been modified to develop global competence (Downey *et al.* 2006). *Working effectively in a second country* and *Interacting with people from diverse cultures / backgrounds* related to this perspective.

Some items were included in response to specific significant studies. *Understanding social and political dimensions of workplaces* was a response to a study of engineering workplace culture and women in engineering by Gill *et al.* (2005), which recommended that engineering education programs should include education about social and political factors in engineering workplaces. *Coordinating the work of others* was inspired by Trevelyan and Tilli's research (Trevelyan and Tilli 2006, Trevelyan 2007). *Using 3D spatial perception or visualization* was included because initiatives have been taken to improve spatial visualization skills of engineering students in order to improve undergraduate performance (Sorby and Baartmans 2000). *Having an action orientation* was recommended in a book on entrepreneurship (Bodde 2004).

Individuals inspired two competencies: *Being concerned for the welfare of others in your organization* (M. Connell, Exec GM HR, Thiess, telephone conversation 2005) and *Making decisions within time and knowledge constraints* (Air Vice Marshal J. Hammer, “Leadership: Making a Difference”, breakfast speech for Western Australian Division, Engineers Australia, 2004). *Recognising unrealistic results* was added to the *Practical engineering* item after being emphasised by His Excellency Dr Ken Michael, AC (meeting with UWA Engineering Learning and Practice Research Group, 7 June 2006). *Focusing on your organization’s needs* was identified by participants in the panel session reported in Chapter 4.

Computer literacy appeared in earlier studies (for example, Lang *et al.* 1999) but was not included in this study because computers are now considered to be everyday tools, like calculators and pens, for graduates.

3.3. Refinement of Competency Items for the Questionnaires

The questionnaire for Survey 1 was developed as recommended by Raymond (2005) with additional reference to survey methodology (Suskie 1998, Dillman 2000, Fink 2003). Obtaining sufficient survey responses (or participants who complete the questionnaire) to achieve required statistical power, and representation in the sample, is essential to the success of surveys. One of the many ways to maximise the response rate is to reduce the time and effort required to complete the questionnaire (Porter 2004). This can be achieved by reducing the number of questions, and by making the questions clear and concise. These must be balanced with the need to include questions that are essential to the research, and the need to achieve sufficient accuracy and reliability in the responses. Too many questions, or questions that take too long to read, can damage the response rate by deterring participants, and can reduce the reliability of responses because participants lose commitment towards the end. Too few

words could reduce the reliability of responses by reducing the reliability of the participants' interpretations of the questions. For these reasons, throughout the survey design the burden on participants was minimised while seeking to optimise reliability.

The competencies were rationalised to 64 items with minimised word length, while optimising clarity. Despite the resulting burden on participants, extra information such as examples and interpretations were included to improve reliability. Brackets and italics indicated to the survey participants any extra pieces of information so that participants could decide whether they needed to read them. An example demonstrating this is, "Having an action orientation (*e.g. avoiding delays, maintaining a sense of urgency*)". People who tested the questionnaire for Survey 1 (Chapter 5) commented that the "optional" information was helpful and it is believed it reduced the number of questions participants missed.

A result of minimising the number and description length of items and limiting the specificity of items was that some items were composites of two items combined with "and" or "or". Examples are, *Speaking and writing fluent English* and *Applying mathematics, science or technical engineering theory or working from first principles*.

In many cases "/" was used in place of "or" for brevity. Examples are *Generalising/abstracting concepts* and *Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems*. The use of composite items such as this is not usually recommended survey methodology because respondents may differ in the way they rate a composite item formed from individual items that they would not have rated equally. This introduced a risk to the reliability of responses. However, it was assumed that the participating engineers would interpret "and" and "or" consistently, using the words' meanings as logic operators. By combining items, precision was reduced. In the balance, given the nature of the participants, forming composite items reduced the number of items, and minimal risk to the reliability of responses was anticipated.

A concern was that participants would over-estimate the importance of the competencies, thereby making it difficult to discriminate between competencies with different relative importance (Morgeson and Campion 1997). The structure of the survey was designed to use order effect (Dillman 2000). McFarland (2004) tested the effects of question order and concluded that asking specific behavioural questions, before asking general questions, strengthened the relationship between the responses to the general and specific questions by providing concrete references. The competencies were placed after the questions on work context and tasks to force participants to think about the true nature of their work before rating the competencies. As recommended by Morgeson *et al.* (2004) the competencies were listed as verbs so that participants had to consider whether they actually perform them.

Many of the competency items were worded in ways to discourage automatic high ratings of importance, by including adjectives to indicate that the competency referred not just to performing an action, but to performing the action at a high level. Examples were “Using *effective* graphical communication” and “Acting within *exemplary* ethical standards”.

Similarly, to reduce over-estimation of importance, competency items were operationalised using concrete rather than abstract words. This is recommended by Fink (2003). For example, “creativity” was broken into less abstract components including *Thinking critically to identify potential possibilities for improvements*, *Thinking laterally / using creativity/initiative/ingenuity*, *Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems*, and *Taking considered risks*. Similarly, “critical thinking” was expanded to *Thinking critically to identify potential possibilities for improvements*.

The competencies were grouped under six headings selected such that they would appear sensible to participants, as recommended by (Dillman 2000), and ordered alphabetically.

Final refinement was made after review by the CEG Project Industry Advisory Committee, which was introduced in section 1.5, and during the survey testing described in Chapter 5.

The final list of 64 competencies, used in the questionnaire for Survey 1, appears in Table 1. The same competencies were used for Survey 2. The only adaptations necessary between surveys were from the second to the third person. For example “your” was replaced with “his/her”.

Table 1. Competencies expected to be important to engineering work, refined to be rated for importance using surveys (references identified in Appendix II)

<i>Group effectiveness/teamwork</i>	
1.	Interacting with people from diverse cultures / backgrounds
2.	Interacting with people in diverse disciplines/professions/trades
3.	Mentoring/coaching co-workers
4.	Working in teams (<i>e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion</i>)
<i>Communication</i>	
5.	Communicating clearly and concisely in writing (<i>e.g. writing technical documents, instructions, specifications</i>)
6.	Managing own communications (<i>e.g. keeping up to date and complete, following up</i>)
7.	Negotiating / asserting/defending approaches/needs
8.	Presenting clearly and engagingly (<i>e.g. speaking, lecturing</i>)
9.	Speaking and writing fluent English
10.	Using effective graphical communication (<i>e.g. reading drawings</i>)
11.	Using effective verbal communication (<i>e.g. giving instructions, asking for information, listening</i>)
12.	Working effectively in a second country
<i>Creative thinking / problem-solving</i>	
13.	Applying mathematics, science or technical engineering theory or working from first principles
14.	Appreciating aesthetic features of design
15.	Being familiar with complete lifecycle of projects/programs/products

16. Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in his/her discipline of engineering (*e.g. ability to recognise unrealistic results*)
17. Evaluating / advocating for / improving maintainability
18. Evaluating / advocating for / improving manufacturability
19. Evaluating / advocating for / improving sustainability and the environmental impact (*local/global*) of engineering solutions
20. Evaluating reliability / potential failures
21. Evaluating the impact of engineering solutions in the social/cultural/political contexts (*local/global*)
22. Generalising/abstracting concepts
23. Modelling/simulating/prototyping and recognising the limitations involved
24. Solving problems (*e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs*)
25. Sourcing/understanding/evaluating information
26. Thinking critically to identify potential possibilities for improvements
27. Thinking laterally / using creativity/initiative/ingenuity
28. Trying new approaches/technology / capitalising on change / initiating/driving change
29. Using “simultaneous engineering design and development” / “integrated product and process design” / “collaborative engineering”
30. Using 3D spatial perception or visualization (*e.g. visualizing various perspectives*)
31. Using a systems approach
32. Using design methodology (*e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating*)
33. Using research / experimentation techniques / scientific method

Organizational effectiveness / leadership

34. Actively promoting diversity within your organization (*e.g. culture, religion*)
35. Applying familiarity with risk/liability/legislation/standards/codes / IP issues
36. Applying familiarity with the different functions in your organization and how these interrelate
37. Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
38. Chairing / participating constructively in meetings (*e.g. team meetings / forums /workshops / focus groups / interviews*)
39. Coordinating the work of others
40. Engaging in entrepreneurship / innovation / identifying and commercialising opportunities
41. Evaluating marketing issues / applying a customer focus
42. Evaluating / advocating for / improving health and safety issues
43. Focusing on your organization’s needs
44. Leading (*e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others*)
45. Making decisions within time and knowledge constraints

- 46. Managing (*e.g. projects/programs/contracts/people /strategic planning/performance/change*)
- 47. Networking (*i.e. building/maintaining personal/organizational networks*)
- 48. Supervising work/people
- 49. Taking considered risks
- 50. Understanding social and political dimensions of workplaces

Self-management / personal style / life-long learning

- 51. Being positive/enthusiastic/motivated
- 52. Engaging in active citizenship (*e.g. being involved in the local / national or international community / engaging in public debates*)
- 53. Having an action orientation (*e.g. avoiding delays, maintaining a sense of urgency*)
- 54. Keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials
- 55. Managing information/documents
- 56. Managing personal and professional development (*e.g. self directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively*)
- 57. Managing self (*e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health*)

Work-related dispositions and attitudes

- 58. Acting within exemplary ethical standards
- 59. Being committed to doing your best
- 60. Being concerned for the welfare of others in your organization (*e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution*)
- 61. Being concerned for the welfare of the local, national and global communities
- 62. Being loyal to your organization (*e.g. representing it positively*)
- 63. Demonstrating honesty (*e.g. admitting one's mistakes, giving directors bad news*)
- 64. Presenting a professional image (*i.e. demeanour and dress*) (*e.g. being confident/respectful*)

These competencies were rated for importance by established engineers in Survey 1, and senior engineers in Survey 2.

CHAPTER 4. Development of a Task Inventory for Engineers Working in Research and Development

4.1. Introduction

Within the theoretical framework and methodology detailed in Chapter 1, competencies are understood to be manifested in responses to demands in a context. Therefore, the method was designed to identify competencies required by engineers and also to discover whether the required competencies varied significantly across the engineers' tasks and the context of their work. For this reason, Survey 1 collected not only ratings of importance of competencies, but also data about the tasks and work context of the engineers. Therefore, a task inventory was developed.

4.2. Method

The task inventory asked participants "To do your current job well, which of the following tasks must you do?" As previously noted, the Engineers Australia *National Generic Competency Standards: Stage 2 for Professional Engineers* (IEAust 1999b) were adapted to form the basis of the task inventory. The tasks were grouped under headings adapted from the units of competence. As recommended by Raymond (2005) and job analysis methodology, the imperative mood was used, for example, *Identify constraints on potential engineering solutions*.

It was not clear that the Stage 2 Competencies included all of the tasks performed by engineers working in research and development. Therefore, a panel session was held to discover whether there were additional tasks performed by engineers working in research and development.

The panel session was held on 11 August 2005, in the Electrical and Electronic Engineering Building at UWA. The method was adapted from job analysis techniques (McCormick 1979, Fine and Getkate 1995, Schippmann 1999).

4.2.1. Recruitment of Panel Session Participants

Potential participants were selected to include a balance from academia and outside university, gender balance, diversity of disciplines, diversity in the size of organizations for which people worked, and representation from both private organizations and a government subsidised organization. Invitation letters, accompanied by information sheets, were posted to twelve selected potential participants (Appendix IV, Appendix V). Nine people attended. Four were unavailable on the chosen date and one of these invited a substitute from his organization, as suggested in the invitation.

4.2.2. Demographic Details of Participants

The participants each completed a biographical questionnaire (Appendix VII), confirming diverse backgrounds for which the participants were selected (Table 2).

Table 2. Demographic details of participants in panel session to collect tasks of established engineers in research and development

<i>Demographic variable and values</i>		<i>Number of participants</i>
<i>Gender</i>	Masculine	5
	Feminine	4
<i>First degree</i>	Bachelor of Engineering	7
	Bachelor of Science (Computer Science)	1
	Bachelor of Arts (Metallurgy and Materials)	1
<i>Highest degree</i>	doctorate	6
	bachelor	1
	honours	1
	master of business administration	1
<i>Disciplines in which qualified</i>	electrical/electronic/computer systems	3
	mechanical	3
	civil	2
	computer science	1

<i>Country of first degree</i>		
	Australia	6
	England	1
	Canada	1
	Ireland	1
<i>Types of organization in which participants had worked</i>		
	university	6
	government R&D	3
	private R&D	5
<i>Numbers of engineers in organizations in which participants had worked</i>		
	< 10	3
	10-99	5
	100	4

Notes:

- While most of the participants completed their first degrees in Australia, additional countries in which the participants completed subsequent degrees include England, Japan and the USA. Participants had worked in Canada, China (including Hong Kong), Germany, Ireland, Japan, Singapore, Thailand, the UK, and the USA. The participants' years of involvement in research and development varied from 6 to 34 with an average of 18 years.
- At least one participant had experience in each of the following engineering industries: basic metal products, chemical and petroleum, communication, maintenance, consulting and technical services, defence, education, industrial machinery, mining or quarrying, non-metallic minerals, oil/gas exploration/production, scientific equipment, transport and storage, water sewerage and drainage, wood and paper products, business systems, offshore and ocean.

4.2.3. Panel Session Procedure

There were significant features of this application of job analysis which made it different from many other applications. Firstly, this study was concerned with a wide variety of jobs. Engineers with five to twenty years' experience can be doing any one of many different jobs, even within research. Secondly, the study was concerned with a wide variety of organizations. Different organizations provide different contexts requiring different competencies of engineers. Thirdly, the purpose was to establish a list of tasks to form the basis of a task inventory to be rated in the next phase of the overarching research plan. These features determined the procedure.

The panel session was designed to be achievable and suitable for the purpose. In order to manage the wide variety of jobs and workplaces in the scope of this study, a simplified adaptation of job analysis was used. Detailed job analysis methods identifying tasks to a high level of specificity were not practical. Fine and Getkate (1995) estimated that it usually takes more than two days to conduct a job analysis group interview to describe one job. This time was not available for every different type of job in the scope of this study, and if it had been, the resulting list of tasks would have been too long to include in a survey. A main difference between methods described in the human resource management literature and this study, was in the level of specification expected in the responses.

Guiding questions (Appendix VIII) were emailed to the participants three days before the session. The questions and structure of the panel session were an adaptation of the questions on outputs and tasks recommended by Fine and Getkate and the questions recommended for a short version of competency modelling described by Spencer and Spencer (1993). The panel session lasted an hour and a half. Most of the discussion was at the level of task outputs, rather than detailed tasks.

4.2.3.1. Guiding Questions for Panel Session to

Develop a Task Inventory for Engineers Working in Research and Development

- 1) What are the outputs/objectives for which an established research and development engineer is paid, i.e. which contribute to the organization in which the engineer works?
- 2) In addition to (1), what are the outputs/objectives that an established research and development engineer seeks to achieve in order to contribute to the success of the engineer's career?

- 3) What does a research and development engineer do to achieve each of the outputs/objectives identified in response to the above questions?

The purpose of the session was outlined, and the desired form of task statements described. The questions moved from job outputs to more specific tasks, focusing on the above questions. Participants' responses were displayed by data projector, allowing participants to read and comment throughout the session. The session was video recorded.

The participants' responses were refined by removing redundancies and ambiguities and levelling the specificity, as recommended by Raymond (2005).

4.3. Results: Tasks Identified in the Panel Session

The identified tasks are listed below (Table 3). As noted in the table, some of the items raised by the panel were competencies rather than tasks.

Table 3. Outputs and tasks of established engineers in research and development as identified by panel

Output 1. Research papers

- Develop and verify original ideas
- Identify viable opportunities
- Marshall thoughts

Output 2. Patents

- Develop, validate and verify original ideas
- Establish/demonstrate originality
- Identify viable opportunities
- Write application
- Communicate with scribe
- Marshall thoughts

Output 3. Design products

- Identify product need (market research)
- Evaluate available technology
- Specify performance
- Establish parameters
- Establish constraints
- Acquire relevant additional knowledge
- Establish feasibility through sourcing and costing components
- Assess suitability, evaluate critically, and choose between alternative innovations

- Design and develop prototype
- Test performance
- Establish manufacturing process/sequence
- Develop product to deliver impact

Output 4. Attract funding (internal and external)

- Write proposals
- Develop business plans (cost-benefit analysis)
- Identify potential benefits from the research
- Identify sources
- Do market research
- Identify key objectives of prospective funding bodies
- Understand structure and process of funding bodies
- Identify benefits to potential sponsors
- Demonstrate benefits to society
- Communicate across disciplines [more a competency than a task]
- Establish and maintain track record
- Advocate and influence
- Develop relationships
- Assess sustainability of solutions
- Consult society for impact
- Communicate impact and benefits of solution to society

Output 5. Commercialise

- Create commercial entities (i.e. companies)
- Shape marketing ideas into feasible products (product shaping)

Output 6. Demonstrate expertise in specialty

- Recognise strengths
- Make decisions for career
- Continue professional development
- Manage portfolio
- Maintain transferable skills
- Establish credibility

Other Tasks

- Monitor and maintain profit margins
- Manage the budget
- Attract co-workers
- Build teams – form teams of people
- Generate/initiate projects
- Bring in new techniques/approaches to development
- Identify emerging technologies
- Maintain awareness of international trends
- Influence technological directions pursued by company
- Develop standards and contribute to standards bodies
- Identify problems
- Develop solutions to problems
 - Investigate solutions
 - Test solutions
- Document products / track processes
- Capture and manage knowledge

- Define requirements
- Design high level architecture (perhaps another word will generalise this beyond software engineering)
- Manage projects
- Develop relationships with other organizations and community
- Mentor and role model
- Focus on Key Performance Indicators – more a competency than a task
- Maintain focus [more a competency than a task]
- Discipline [more a competency than a task]
- Manage technical performance
- Manage people
- Train people
- Participate in community education and engagement
- Contribute to knowledge
- Communicate with peers
- Interact with people from all levels

Two new items that had not been recognised elsewhere arose during the panel session discussion. These were the additional task, form teams of people, and the competency, *Focusing on your organization's needs*. During the panel session, participants discussed how people form teams by building their credibility and that technical expertise in at least one area is part of this. Despite this long-term investment, “form teams of people” was considered to be a task because it is an activity with an objective. *Focusing on your organization's needs* was considered to be a competency because it is a combination of skill and attitude that is used to complete tasks.

4.4. Opportunity for Further Research

Question 3 of the guiding questions for the panel session, “In addition to (1) and (2), what are the outputs/objectives that a research and development engineer seeks to achieve in order to contribute to the well-functioning of society?” was not covered within the time and was excluded from the scope of the CEG Project. This was consistent with adopting Definition 2 for generic engineering competencies, rather than Definition 1, as described in the Introduction (section 1.7.1.4). Exclusion of these did not exclude consideration of the needs of society; engineers’ work should place the welfare of the community first at all times, as required by *Engineers Australia's Code of*

Ethics (IEAust 2000). Hence, the items excluded from the scope were only those needed solely for society and not for the employer or the engineer. The identification of tasks needed by engineers for the welfare of society, although not for engineers' work or their careers, is an opportunity for future research.

4.5. Implications of the Results

4.5.1. Implications for the Survey of Established Engineers

The competency *Focusing on your organization's needs* was included in the list of competencies rated for importance by surveyed engineers. The task, form teams of people, was included in the task inventory in the survey of established engineers. These tasks were grouped based on the competency standards from which they were adapted.

The task, form teams of people, could have been placed with other tasks relevant to doing research. However, the task was considered to be relevant to many engineers regardless of whether they are working in research. Therefore, this task was added to the engineering practice group of tasks. This decision was justified by the survey results. As expected, of the participants who reported that they must do at least half of the research/development/commercialisation tasks to do their jobs well, most (75%) also selected the task, form teams of people. However, only 16% of the participants who selected the task, form teams of people, also selected at least half of the research/development/commercialisation tasks and 46% of those who selected the task, form teams of people, selected none of the research/development/commercialisation tasks. Therefore, the survey results suggested that, first, as suggested by the panel session participants, most engineers doing research/development/commercialisation need to form teams, and second, many other engineers form teams.

4.5.2. Recommendation for Competency Standards

The task, form teams of people, was identified by research engineers and selected by engineers as a task they must perform to do their jobs well. Engineers Australia could consider adding to its competency standards a new item on forming teams of people.

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CHAPTER 5. Method for Surveys

The development, implementation, and data screening for the two large-scale surveys in the CEG Project are described here. Participant demographic details, results, analysis and discussion, are presented in Chapter 6.

5.1. *Survey 1 of Established Engineers on Their Work and Required Competencies*

5.1.1. Introduction

This survey was designed to select the competencies that are important to engineers' work from those identified in the literature. In accordance with the Project's theoretical framework and methodology, it was expected that engineers' perceptions of competencies would be influenced by their tasks and work context, and also by personal characteristics of the individuals making the ratings. Therefore, in Survey 1, established engineers were asked to rate competencies and also to answer questions about their tasks, work context, and personal factors.

Survey 1 was the main data collection phase of the CEG Project. Other phases were undertaken to prepare for this phase or validate its outcomes. Survey 1 addressed the two main research questions about the generic engineering competencies required by engineers graduating in Australia, and the generic engineering competency factors. It also addressed the first two sub-questions, about consistency with accreditation requirements, and a relationship between the nature of engineering work and the required competencies.

Being a large-scale quantitative study, results of Survey 1 can be generalised. Analysis showed that it can be generalised within Western Australia, to Queensland, and possibly across Australia (Chapter 6).

5.1.2. Methodology

Although the DeSeCo Project, from which the theoretical framework was adapted for the CEG Project, noted that the importance of competencies is dependent on the stakeholder, detailed specification of the stakeholder for whom the competencies were important was not stipulated in the questionnaire. It was assumed that participants considered the importance as perceived by themselves, taking into account the needs of their organizations and the community.

The study was conducted in Western Australia. It was designed to answer questions in the context relevant to engineering practice and training programs in Australia. The participant demographics and implications for generality of the results across Australia are detailed with the survey results in Chapter 6.

5.1.3. Method

5.1.3.1. Structure of Questionnaire for Survey 1

Survey 1 was an adapted “practice analysis questionnaire” (Raymond 2005). The survey had five sections (Table 4). Sections III and IV were based on job analysis. Section V was related to competency modelling, with the significant exception that no attempt was made to select high achievers. The sections are discussed in further detail below.

Table 4. Structure of questionnaire for Survey 1 of established engineers with 5 to 20 years’ experience

<i>Section</i>	<i>Topic</i>	<i>Number and type of questions</i>
I	Graduate Attributes	2 brief open questions
II	Demographics	16 closed questions
III	Work Context	36 closed, 2 brief open questions
IV	Tasks (based on Stage 2 Competencies developed by EA)	12 areas with up to 14 tasks per area from which to select
V	Competencies	64 competencies to rate

Section I confirmed to the participant the nature of the questionnaire, gained the participant's interest, and demonstrated to the participant that his or her experience was valuable to this research. It asked whether there was a competency that the participant would have liked to gain from his or her engineering studies and whether there was a competency the participant had observed to be lacking in recent engineering graduates.

Section II included questions about the education, personal background, and engineering experience of the participant. Section III asked about the organization in which the participant worked and the nature of the participant's work. Several of the questions in Sections II and III were adapted from a survey by the Association of Professional Engineers, Scientists and Managers Australia (APESMA) and EA (2005). A question asked about the organizational structure of the organization in which the participant worked. This was included because Lam (1994) described how the different organizational structures in Japan and Britain were related to different engineering practice.

Section IV was a task inventory. One item was identified in the panel session (Chapter 4) and the others were adapted from the Stage 2 Competencies (IEAust 1999b). The Stage-2 Competency, *Self-management in the Engineering Workplace*, was not adapted as a task because it was seen as an approach rather than a task with its own objectives. An additional task, teaching/training, was created because this was identified as performed by engineers, but missing from the tasks adapted from the Stage 2 Competencies. Section IV asked "To do your current job well, which of the following tasks must you do?"

Section V asked participants "How important is each of the following to doing your job well?" using a five-point rating scale where 1 = *not needed* and 5 = *critical*. The development of the items in Section V was discussed in Chapter 3.

The word “well” was included in the question “How important is each of the following to doing your job *well*?” to indicate an overall high level of job performance. The competencies a stakeholder desires in an engineer vary depending on the performance indicator. For example, one engineer could increase short-term profit for a company, while an engineer with different competencies could improve the company’s long-term client relationships. While reliability of the survey might have been improved if the questionnaire had stipulated performance indicators for which importance of competencies was to be rated, in the interest of minimising the burden to participants, this specification was limited to a level indicated by the word “well”.

5.1.3.2. Survey Development

5.1.3.2.1. Rating Scale for Importance of Competencies

Dimensions of Importance

Raymond compares possible rating scales and combinations of scales. The “importance” of competencies has multiple dimensions. For example, importance could be measured in frequency of use of the competency, duration of use of the competency, consequence of not having the competency, difficulty of the competency, or percentage of engineers who do not have and do need the competency. Raymond discusses options such as asking participants to rate items on multiple scales, and combining the dimensions in the analysis. For example, the survey of established engineers could have asked participants to, “Rate the frequency of use of each competency on a five-point scale where *1 = never or hardly ever* and *5 = hourly or more*, and rate the consequence of poor performance on each competency on a five-point scale where *1 = minimal or none* and *5 = serious jeopardy to the organization or worse*.”

In this study each participant was asked to rate the “importance” of performing each competency item to doing his or her job well. No dimensions of importance were

specified. The limit to one rating scale was designed to minimise burden on participants. It was assumed that participants mentally generalised over multiple dimensions of importance to rate the competency items.

Anchor Descriptors

Anchor descriptors stipulate the meanings of points on rating scales. This study asked each participant to rate the importance of each competency item to doing his or her job well, on a five-point rating scale where *1 = not needed* and *5 = critical*. No point was labelled “No opinion” because there would have been no realistic circumstance in which an engineer would not have an opinion. Other studies such as Ferguson’s (2006a) stipulate anchor descriptors for every point on the scale. Anchor descriptors for every point on the scale might improve reliability by improving the likelihood that participants share similar interpretation for each point on the scale. However, in this study anchor descriptors were stipulated only for the endpoints of the scale. Anchor descriptors would have needed to stipulate a dimension of importance such as discussed in the previous section. Descriptors such as *3 = important* and *4 = fairly important*, which do not specify the dimension of importance, would not necessarily have spaced the points on the scale evenly. The restriction of anchor descriptors for the scale’s endpoints only, was assumed to imply, for analysis purposes, that the points between the endpoints were evenly separated.

As multiple dimensions of importance were relevant to this study, the use of anchor points specifying the dimensions of importance would have lead to the need for multiple scales. Avoiding descriptors, except at the endpoints of the scale minimised the visual clutter on the questionnaire and again reduced burden on the participants. The participants could then mentally derive the intermediate points on the scale based on the dimensions of importance they had adopted.

5.1.3.3. Implementation and Testing

The questionnaire was refined with advice from the CEG Project Advisory Committee, comprising senior engineers from industry. The survey was implemented online because this was expected to be most convenient for participants. Online implementation had two other advantages. The first was that it facilitated recruitment of volunteers through newsletters without the need to post out questionnaires. This introduced an anticipated side-effect resulting from participants self-selecting (Umbach 2004). Some participants did not have the desired number of years' experience. Responses from these people were identifiable. A second advantage of online implementation was that it avoided data entry, hence saving time and removing an opportunity for the introduction of errors.

The survey was implemented on the UWA website using the MySource Classic web content management system. A valuable feature that is unavailable on paper questionnaires was the ability to disallow multiple responses to one question. The feature that denied continuation without answering a specific question was also used, although sparingly to avoid causing frustration.

For clarity, the questions were in bold font, and the question numbers and response options in normal font and instructions in italics. Also to avoid confusion, rather than restarting the question numbers for each section, the question numbering continued throughout the questionnaire.

Seven established engineers tested the questionnaire online and completed a test rubric (Appendix IX). The questionnaire was refined iteratively, seeking further evaluation from the testers after improvements were made. Although Dillman recommended placing demographic questions towards the end of questionnaires because they are boring, the testers expected these questions early because this was familiar to them. The testers asked for clearer distinction between the competency items. Consequently alternate items were coloured blue throughout the questionnaire.

The tests found that the questionnaire would take 20 to 30 minutes to complete. This was considered satisfactorily short.

The online questionnaire is presented in Appendix X.

5.1.3.4. Recruitment of Participants

Calls for volunteer participants were placed in newsletters of the Western Australian (WA) Division of Engineers Australia, the Institute of Electrical and Electronic Engineers WA section, and the newsletter for past engineering graduates of UWA (Appendix XI). A call was distributed by email through the National Women in Engineering Committee of Engineers Australia and the WA Women in Engineering Panel of Engineers Australia. Members of industry advisory boards within the engineering faculty, and the research Project's Industry Advisory Committee were asked to distribute the internet address for the survey. The Dean of Engineering at UWA wrote to the 2542 graduates who completed bachelor of engineering degrees at the University in the years 1985 to 2001, inviting them to participate in the survey (Appendix XII). Participants were invited to enter a draw for an mp3 player and to receive a report on the results. Participants provided email addresses to take up this offer. However, survey responses were anonymous. The information sheet for participants, required for ethics approval, was posted with letters and also available online and accessible from the survey welcome page (Appendices XIII and XIV).

On reflection, the questionnaire length could have reduced the response rate. Although the number of participants did provide the required statistical power, the response rate was poor. A second likely reason for the low response rate is that most of the calls for volunteers were on paper and the questionnaire was online. Consistency between the media used to call for volunteers and to implement the questionnaire might have improved the response rate. Both factors were improved for Survey 2.

5.1.3.5. Data Screening

Approximately 50 responses were removed from the data. The majority of exclusions were made because the respondents had indicated fewer than five or greater than twenty years' experience since graduation. Several responses were excluded because the respondents had missed a high number of questions. Any responses with more than five competency ratings missing were excluded. Three hundred valid responses remained.

Among the retained responses, only a very few competency ratings were missing from any one participant. Forty-two of the competencies were rated by all 300 participants. Of the remaining competencies 16 were rated by 299 of the participants, 5 by 298 participants and 1 by 296. Given the very low numbers of missing values (30 values or 0.2% among 300 ratings of 64 competencies), a large number of ratings would have been lost if an entire participant's response had been deleted whenever a participant missed a competency rating. Instead of deleting valuable data due to very low numbers of missing ratings, missing ratings for each competency were replaced with the median of the valid ratings for that competency.

5.1.3.6. Data Coding

The data were coded by allocating labelled numbers to response options in preparation for analysis in SPSSTM. Response options that were selected by too few (below ten) respondents were combined with consecutive response options if conceptually reasonable. Questions that allowed selection of multiple response options and questions with *other* as an option required decisions in order to be coded. These are listed in Appendix XV.

Participants' demographic data and results for Survey 1 are reported with those for Survey 2, in Chapter 6, following Survey 2's method in the remainder of Chapter 5.

5.2. Survey 2 of Senior Engineers, to Confirm

Outcomes of Survey of Established Engineers

5.2.1. Introduction

Survey 1 asked established engineers, with five to twenty years' experience, about the competencies required for their work, and their tasks and work context. The purpose was to identify generic engineering competencies and factors among these. Tasks and work context data were collected to discover whether there was a relationship between these and the required competencies. Survey 2 validated the outcomes of Survey 1.

Participants in Survey 1 were job incumbents for the jobs of interest to this study. Therefore, they were expected to know their jobs better than anyone else. However, unlike common practice in competency modelling, in the CEG Project there was no attempt to select only superior performers among the job incumbents. Therefore, as recommended for job analysis, expert opinions were required to confirm the opinions of the job incumbents. Survey 2 achieved this by surveying senior engineers, who had experience managing or supervising engineers with five to twenty years' experience.

5.2.2. Method

5.2.2.1. Structure of Questionnaire for Survey 2

Survey 2 was shorter than Survey 1, with only two sections: Section I containing 16 closed questions on demographic details and work context, and Section II similar to Section V in Survey 1, in which the 64 competencies were rated on importance.

Additionally, there was an opportunity for comment at the end of the online questionnaire and engineers commented anywhere on the paper questionnaire. Section I included questions about the senior engineer's qualifications and experience. Section II asked the senior engineer to rate the importance of competencies for a typical engineer

in a specific established engineer's role (Table 5) about which the senior engineer participant was familiar. The competency items and scale in Part II of Survey 2 were the same as in Part V of Survey 1, except that the competencies in the second survey referred to "his/her" where the first survey referred to "your". The second survey included few questions that referred to work context and no task inventory. Appendix XVI presents the paper version.

Table 5. Comparable features of Surveys 1 and 2

<i>Feature</i>	<i>Survey 1</i>	<i>Survey 2</i>
<i>Purpose</i>	To profile the work and required competencies of established engineers	To confirm outcomes of Survey 1 of established engineers
<i>Participants</i>	Engineers with 5 to 20 years' experience since graduating from an engineering degree of 4 years or more	Senior engineers experienced in managing, supervising or directing engineering teams that had included engineering graduates with 5 to 20 years' experience since graduating from degrees of 4 years or more. It was stipulated that participants should have more than 20 years' experience.
<i>Topic of demographic questions</i>	Participant's current job and organization	"Most" of the participant's experience, "main" discipline in which experienced, "main" organization in which experienced, etc
<i>Question on key responsibilities</i>	"What are the key responsibilities in your position?"	"Please think of a specific typical job performed by a graduate engineer with 5 to 20 years' experience, in the main organization in which you are experienced. What are the key responsibilities of the typical job?"
<i>Question asking for competency ratings</i>	"How important is each of the following to doing your job well?"	"In the previous section you referred to a specific typical job performed by a graduate engineer... How important is each of the following for an engineer to do the typical job well?"
<i>Implementation</i>	Online	Online or on paper
<i>N</i>	300	250

5.2.2.2. Implementation and Testing

The questionnaire was reviewed by the CEG Project Industry Advisory Committee. All members of the Committee were senior engineers suitable to participate in the survey. Additionally, the questionnaire was tested on paper by four senior engineers. The requirement that participants have at least 20 years' experience was added partly to avoid confusion with Survey 1. The survey was implemented online and on paper and took less than 15 minutes to complete either way.

5.2.2.3. Recruitment of Participants

The Dean of Engineering wrote to 1273 engineering graduates from suitable cohorts from UWA, inviting participation (Appendix XVII). An information sheet (Appendix XVIII), consent form (Appendix XIX), questionnaire on yellow paper, and reply-paid envelope were enclosed and a link to the online questionnaire was included. Volunteer participants were recruited also by email from the (Australian) Project Management Forum and the university's industry advisory groups. One participant was invited to participate despite having only 15 years' experience, because he was the manager of the Northern Territory and WA region of a large engineering organization. Participants were offered a report and invited to provide their names if they wished to be acknowledged.

Unfortunately the consent form probably limited the number of participants who agreed to be acknowledged by name. It became apparent that the words intended to invite the participants to provide names for acknowledgement discouraged some engineers. The consent form included a line that read, "I wish to be acknowledged in the PhD Thesis as _____". Several engineers changed this to words such as "I may be acknowledged if you wish, as _____" which implied humility, unlike the original version. Many of the senior engineers chose to write their names and contact details on

the questionnaires, particularly if they had included comments. This was not assumed to imply consent to acknowledge them by name.

The response rate was much better than for the first survey. The high proportion of responses on paper, rather than online, has been observed in other surveys (Lang 2007). Potential reasons for the better response rate are a stronger interest in the topic among the senior engineers, the shorter time to complete the second questionnaire than the first, and the implementation of the second survey on paper which was consistent with recruitment of participants by post and which was used by the majority of participants.

5.2.2.4. Data Screening

Two hundred and fifty-six responses were received. Of these, 42 were online and 214 on paper. Completed paper questionnaires were numbered on receipt, to enable checking of entered responses in the computer with the raw responses on the questionnaires. Six paper responses were excluded for the following reasons. One participant selected ratings between points on the rating scale. One rated competencies by selecting two points on the scale, instead of one. Four indicated insufficient experience. Two hundred and fifty usable responses remained.

The maximum number of competency ratings missed by any one person was four. The total number of competency ratings missed among all 250 participants' ratings for the 64 competencies was 44 (0.3%). In the response from any one participant, only a very few competency ratings were missing. Thirty-six of the competencies were rated by all 250 participants. Of the remaining competencies, 15 were rated by 249 of the participants, 11 by 248 participants and one competency each by 247 and 246 participants. As in the first survey, missing ratings for each competency were replaced with the median of the valid ratings for that competency. Medians were calculated across the sample of senior engineers.

Demographic data and results for Survey 2 are presented in Chapter 6 with those for Survey 1.

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CHAPTER 6. Survey Results and Analysis at the Item-Level

6.1. *Background*

Chapter 5 described the method for Surveys 1 and 2. The survey responses are now discussed. This includes analysis of demographic characteristics of the participants, data about jobs performed by engineers with five to twenty years' experience, and ratings of the importance of competencies for these jobs. The competencies are grouped into factors in Chapter 7, allowing investigation of relationships between the factors and features of the engineers and their work in Chapter 8.

6.2. *Research Questions*

This chapter addresses the first main research question:

What are the generic engineering competencies that engineers graduating in Australia require for their work as engineers?

It also addresses the first sub-question:

Are the engineering program outcomes currently required for accreditation in Australia aligned with the identified generic engineering competencies?

Initially, the characteristics of the survey participants who rated the competencies, and of the established engineers' jobs for which competencies were rated, are described. With this background, the competency gaps identified in response to the two open questions at the start of the questionnaire for Survey 1 are summarised. Finally, the ratings of importance of the competencies from both surveys are analysed.

6.3. Characteristics of Participants and Jobs

6.3.1. Significance of Characteristics of Participants and Jobs

Awareness of characteristics of the participants in surveys assists with assessment of the extent to which samples are representative, and the generalisability of results.

Demographic data also help others to assess the potential for transfer of results to their contexts.

In the CEG Project, the characteristics of the engineers' jobs, for which competencies are rated, are important because, within the theoretical framework, the jobs are seen as the demands for which the generic engineering competencies are required. It was expected that there might be significant relationships between the characteristics of the engineering jobs (tasks and work context) and the required competencies, and even that different constellations of weighted generic engineering competencies might be required for different engineering jobs. This would affect the application of the results of this study to program evaluation.

The characteristics of the engineering jobs play a third important role in the CEG Project. In several cases they are used to check the validity of results from other parts of the research. For example, the percentage of people who stated that they communicated using sketches, drawings, charts, diagrams or graphs in Section III of the questionnaire, is later compared with the ratings of importance for the competency *Using 3D spatial perception or visualization*.

6.3.2. Demographic Characteristics of Participants in Surveys 1 and 2

The engineering disciplines in which the survey participants were educated are roughly equally divided between three main categories related to civil, mechanical and electrical

engineering (Table 6). Most of the engineers studied engineering in Australia and most completed their secondary education in Australia. The participation of engineers who had studied outside Australia was welcome because this reflected the diversity among engineers in Australia, and diversity of standpoints was expected to improve the breadth of responses. A limitation of the sample was that most of the engineers studied engineering at UWA. This could have affected the results if, for example, engineering education at UWA gives students different long-term perspectives from those of other engineering students, or if engineers who graduated from UWA took different jobs and careers from other engineering graduates. Analysis of whether the UWA graduates rated the competencies significantly differently is presented in Chapter 8.

As expected, most of the participants were male. However, the percentage of female participants in Survey 1 (18%) was higher than the percentage of female engineers in the Australian workforce with similar experience, which is below 12% and probably below 8% based on EA membership (EA 2009). The over representation of women is most likely due to recruitment of volunteer participants through the WA and National Women in Engineering Committees of EA. It provided useful statistical power for comparisons across genders. However, the percentage of women in Survey 2, of senior engineers, was predictably low (2%), consistent with the lower percentages of female engineers with over 20 years' experience in Australia (APESMA 2007, EA 2009).

Table 6. Demographic characteristics of participants in Survey 1 of 300 established engineers with 5 to 20 years' experience, and Survey 2 of 250 senior engineers

<i>Demographic variable and values</i>	<i>Responses as % of responses to question</i>			
	<i>Responses</i>		<i>Survey</i>	
	<i>1</i>	<i>2</i>	<i>1</i>	<i>2</i>
<i>Country where participant was awarded undergraduate engineering qualification ¹ / engineering qualification if applicable ²</i>				
Australia	271	244	90	98
Not Australia	29	6	10	2
<i>Country where participant completed secondary education</i>				
Australia	252	232	84	93
Not Australia	48	17	16	7
<i>University that awarded participant's: undergraduate engineering qualification ¹ / engineering qualification if applicable ²</i>				
The University of Western Australia	217	226	72	90
Not The University of Western Australia	83	22	28	9
<i>Engineering discipline in which participant was: qualified ¹ / mainly experienced ²</i>				
Mechanical/aeronautical/materials/mechatronics/metallurgical/naval architecture/chemical	111	56	37	22
Civil/structural/environmental/geotechnical/mining	96	111	32	44
Computer systems/electrical/electronic/communications/software/IT	92	80	31	32
<i>Participant's highest level of technical qualification</i>				
Diploma	0	3	0	1
Bachelor pass	103	123	34	49
Honours	151	48	51	19
Postgraduate	45	76	15	30
<i>Participant's non-technical qualification</i>				
None	270	148	90	59
MBA, DipBCom, etc	29	102	10	41
<i>Gender</i>				
Male	245	246	82	98
Female	55	4	18	2
<i>Age (years)</i>				
25-29	43	N/A	14	N/A
30-34	114	N/A	38	N/A
35-39	83	N/A	28	N/A
40-	60	N/A	20	N/A

Notes: ¹ In survey of established engineers, ² In survey of senior engineers

6.3.3. Demographic Characteristics of Established Engineering Jobs Represented in Surveys 1 and 2

Most participants worked mainly in WA (Table 7). More than ten percent of participants in both surveys were employed, or in Survey 2 were mainly employed, outside Australia. Participation from engineers working outside Australia was welcome because engineers graduating in Australia should be able to, and do, work overseas.

Table 7. Demographic characteristics of established engineering jobs represented in Survey 1 of 300 established engineers with 5 to 20 years' experience and Survey 2 of 250 senior engineers

<i>Demographic variable and values</i>	<i>Responses</i>		<i>Responses as % of responses to question</i>	
	<i>Survey</i>		<i>Survey</i>	
	<i>1</i>	<i>2</i>	<i>1</i>	<i>2</i>
<i>Location where participant: worked ¹ / mainly worked ²</i>				
Western Australia	226	202	75	81
Australia and outside Western Australia	38	11	13	4
Outside Australia	36	35	12	14
<i>Sector in which participant was: employed ¹ / mainly employed ²</i>				
Private	235	160	79	65
Government	51	78	17	32
University/tertiary	13	9	4	4
<i>Size of organization in which participant was: employed ¹ / mainly employed ²</i>				
0-50	51	43	17	17
51-500	46	61	15	25
Over 500	203	144	70	58
<i>Number of professional engineers in organization</i>				
<11	52	56	17	23
11-100	71	68	24	27
101-500	73	67	24	27
>500	104	56	35	23

Notes: ¹ In survey of established engineers, ² In survey of senior engineers

6.3.4. Industries Represented in Surveys 1 and 2

Industries represented were similar to those of WA responses in a 2007 APESMA/EA survey (Table 8).

Table 8. Industries represented in Survey 1 of 300 established engineers, and Survey 2 of 250 senior engineers

<i>Industries in which participant: was mainly engaged¹ / had mainly been engaged²</i>	<i>Number of responses</i>		<i>Responses as % of participants</i>		<i>Responses as % of industry selections *</i>		<i>Responses in APESMA/EA Survey as % of APESMA/EA participants</i>		<i>Responses in APESMA/EA Survey as % of APESMA/EA participants</i>	
	<i>Survey</i>		<i>Survey</i>		<i>Survey</i>		<i>In Aust.</i>		<i>In W.A.</i>	
	<i>1</i>	<i>2</i>	<i>1</i>	<i>2</i>	<i>1</i>	<i>2</i>	<i>Est</i>	<i>All</i>	<i>Est</i>	<i>All</i>
<i>Non-manufacturing</i>										
Consulting/technical services	111	124	37	50	18	20	17	18	20	18
Construction/contract/maintenance	68	102	23	41	11	16	13	13	15	14
Mining/quarrying	84	47	28	19	14	7	6	5	20	18
Oil/gas exploration/production	51	32	17	13	8	5	2	2	11	10
Electricity/gas supply	27	28	9	11	4	4	10	12	4	8
Water/sewerage/drainage	46	56	15	22	7	9	7	9	7	10
Communications (inc. Telstra)	18	35	6	14	3	6	4	4	1	1
Defence	16	13	5	5	3	2	8	6	4	3
Public administration (Federal/State/Local)	14	22	5	9	2	3	9	12	4	6
Transport/storage	11	23	4	9	2	4	3	4	1	2
Education	15	12	5	5	2	2	0	1	0	0
<i>Manufacturing</i>										
Food/beverage/tobacco	5	4	2	2	1	1	2	1	0	0
Wood/furniture / paper products	0	4	0	2	0	1	0	0	0	0
Chemical/petroleum products	32	20	11	8	5	3	2	1	4	2
Non-metallic mineral products	10	10	3	4	2	2	0	0	1	1
Basic metal products	29	14	10	6	5	2	2	1	4	3
Steel production	8	10	3	4	1	2	1	1	0	0

Fabricated metal products	20	22	7	9	3	3	0	1	0	1
Transport equipment (inc. motor vehicles)	11	12	4	5	2	2	4	3	0	0
Photographic/scientific equipment	3	4	1	2	0	1	0	0	0	0
Appliances / electrical equipment (inc. electronic equipment)	20	18	7	7	3	3	2	1	2	1
Industrial equipment / machinery	23	18	8	7	4	3	2	1	1	1
<i>Participant was working for ¹ / Main organization in which participant was experienced was ², a consulting engineering firm</i>	110	93	37	37	N/A	N/A	25	25		

Notes:

- ¹ In survey of established engineers. ² In survey of senior engineers.
- Response options adapted from Association of Professional Engineers, Scientists and Managers Australia (APESMA) / Engineers Australia (EA) “Spring 2005 Professional Engineer Remuneration Survey”. APESMA/EA survey statistics are for responses from engineers with 5 to 20 years’ experience (labelled *Est*) and from all engineers, in the “Autumn 2007 Professional Engineer Remuneration Survey”. These were provided by Dominic Angerame, APESMA.
- *The current study’s participants were able to select multiple industries. Participants in the APESMA/EA survey were asked to select the industry in which they were “mainly engaged”. The 5th and 6th columns of data were calculated as percentages of the industry selections made in the current study, including many cases of multiple selections made by one participant.
- Western Australia (WA) is the state from which the survey was conducted.

6.3.5. Key Responsibilities Represented in Surveys 1 and 2

Key responsibilities were similar to those selected by APESMA/EA survey participants across Australia. Responsibilities represented in Survey 1 were aligned more closely than those represented in Survey 2, to the APESMA/EA survey responses (Table 9 and Figure 1). Management was the key responsibility with the highest representation.

Table 9. Key responsibilities represented in Survey 1 of 300 established engineers, with 5 to 20 years' experience, and Survey 2 of 250 senior engineers

Key responsibilities of participant ¹ / Typical job performed by a graduate engineer with 5 to 20 years' experience, in main organization in which participant was experienced ²	Number of responses		Responses as % of participants		Responses as % of key responsibility selections*		Responses in APESMA/ EA Survey as % of APESMA/ EA participants	
	Survey		Survey		Survey		In Australia	
	1	2	1	2	1	2	Est.	All
Construction supervision	52	109	17	44	8	18	7	7
Design of equip/processes	111	128	37	51	18	21	15	15
Management	178	118	59	47	28	19	34	36
Production/quality/maintenance	49	52	16	21	8	8	9	8
Project study / analysis	112	115	37	46	18	19	13	13
Research & Development (inc. product design /development)	70	43	23	17	11	7	10	8
Sales/marketing	31	22	10	9	5	4	2	1
Teaching/training	23	27	8	11	4	4	0	1

Notes:

- ¹ In survey of established engineers. ² In survey of senior engineers.
- Response options adapted from APESMA/EA "Spring 2005 Professional Engineer Remuneration Survey".
- APESMA/EA survey statistics are for responses from engineers with 5 to 20 years' experience (labelled *Est*) and from all engineers, in the "Autumn 2007 Professional Engineer Remuneration Survey". These statistics were provided by Dominic Angerame, APESMA.
- *The current study's participants were able to select multiple responsibilities. Participants in the APESMA/EA Survey were asked to select the response that best described their "main job responsibility". The fifth and sixth columns of data were calculated as a percentage of the key responsibility selections made, including many cases of multiple selections made by one participant, in the current study.
- WA is the state from which the survey was conducted.

Figure 1. Key responsibilities represented in Survey 1 of 300 established engineers and Survey 2 of 250 senior engineers

6.3.6. Tasks Performed by Engineers in Survey 1

The task inventory in Survey 1 asked the established engineers to, “Select the tasks that you must do to do your current jobs well.” The task inventory responses were broadly aligned with competencies demonstrated by applicants for chartered status in the WA Division of EA (Table 10). The categories of tasks selected by the highest percentages of participants were planning and design, engineering practice, investigation and reporting, project engineering and engineering project management, and business management and development (Figure 2). The task inventory was too detailed to include in Survey 2.

Table 10. Tasks performed by participants in Survey 1 of 300 established engineers with 5 to 20 years' experience

Category of tasks	Participants doing no tasks in category, as % of participants		Participants doing at least one but fewer than half the tasks in category, as % of participants		Participants doing at least half the tasks in category, as % of participants		Percent of chartered status applicants that demonstrated element from which task category was adapted
	n	%	n	%	n	%	
Engineering practice	23	8	85	28	192	64	compulsory
Planning / design	22	7	115	38	163	54	compulsory
Project engineering / engineering project management	36	12	120	40	144	48	58
Engineering operations	136	45	114	38	50	17	14
Business management/development	46	15	202	67	52	17	13
Materials/components/systems or sourcing/estimating of materials/components	121	40	118	39	61	20	21
Environmental management	171	57	68	23	61	20	6
Investigation and reporting	34	11	34	11	232	77	67
Research/development/commercialisation	153	51	115	38	32	11	8
Change / technical development	126	42	57	19	117	39	12
Technical sales / promotion	150	50	88	29	62	21	3
Teaching	187	62	83	28	30	10	N/A

Notes:

- Tasks adapted from *National Generic Competency Standards for Stage 2 and the Advanced Stage Engineer*, Barton, ACT: IEAust, 1999.
- Chartered status data are competency element electives demonstrated by chartered status applicants January 2005 to April 2007 in Western Australia, collated by John McLoughlin, and received from Janice Lake, EA WA.

- Chartered status applicants were required to demonstrate the compulsory units of competency and two elective units. Survey 2, the survey of senior engineers, did not ask about tasks.
- In this study, the task, form teams of people, was included with the engineering practice group of tasks, although this item is not adapted from the Stage 2 competency standards.

Figure 2. Tasks performed by established engineers in Survey 1 (N = 300)

6.3.7. Generalisability of Results from Survey 1

Most (75%) of the participants in Survey 1, of established engineers, worked mainly in Western Australia. The APESMA/EA survey data demonstrate that the mining/quarrying and oil/gas exploration/production industries employed a larger percentage of the engineers in Western Australia than in Australia overall. This was reflected in the industry representation in Survey 1.

There are implications for generalisation of the results beyond Western Australia. It is expected that the results could reasonably be generalised to a state such as Queensland, with similar industries to those in Western Australia. The similarity in the key responsibilities performed by the participants in Survey 1 and the APESMA/EA survey participants (Table 9) suggests that the results of Survey 1 may even be generalised

across Australia. An alternative would be to extrapolate the results to a different context by comparing the competency ratings across subgroups in this study's sample and adjusting results for the different estimated distribution of subgroups in a different context.

6.3.8. Characteristics of Survey 1 Participants' Organizations

According to the theoretical framework, the context in which someone works can affect the competencies required. The second sub-question asks whether the required competencies are related to tasks and work context. The organization is part of the work context.

The organizations, in which the engineers who participated in Survey 1 worked, were established, and most likely to have either very local or very global users of their products or services (Table 11). No organizational structure dominated.

Table 11. Characteristics of participants' organizations in Survey 1 of 300 established engineers with 5 to 20 years' experience

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Years participant's organization had provided its main current service or products</i>		
0 - 3 years	16	5
> 3 years	283	95
<i>Extent to which locations of users of participant's organization were local or global</i>		
Users in 1 or 2 states/provinces in 1 country only	73	25
Users in more than 2 states/provinces in one country	24	8
Users in 2 to 4 countries	32	11
Users in more than 4 countries	168	57
<i>Organizational structure of participant's organization</i>		
Mainly flat	42	14
More flat than hierarchical	55	18
Mixed	64	22
More hierarchical than flat	67	22
Mainly hierarchical	70	24

6.3.9. Additional Features of Work Context of Participants in Survey 1

Characteristics of the organization in which someone works are only part of the work context. Additional data related to the work context of participants are presented here.

6.3.9.1. Extent to Which Participants' Work was Technical

Most engineers considered their work to be at least partly technical (Table 12) rather than entirely non-technical. This was expected and consistent with Trevelyan's (2007) findings. Although engineers spend much of their time interacting with people, this requires technical knowledge and skills.

Table 12. Participants' work contexts in Survey 1 of 300 established engineers: extent to which work was technical

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Extent to which participant's role was technical</i>		
Mostly technical	142	47
Partly technical	130	43
Not-technical or hardly at all	28	9

6.3.9.2. Participants' Places of Work

As noted, users of products and services were reported, for 68% of the organizations in which participants worked, to be in multiple countries (Table 11). However, this did not translate into engineers working in multiple countries. Most (71%) had worked in only one country in the three years leading to participation in the survey (Table 13).

Fifty-one (17%) of the 300 established engineers were spending more than ten percent of their work time in regional, remote or off-shore locations.

**Table 13. Participants' work contexts in Survey 1 of 300 established engineers:
place of work**

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Number of countries in which participant worked during past 2 years</i>		
1	211	71
> 1	87	29
<i>Percentage of participant's work time spent in regional, remote or offshore locations</i>		
0 - 33%	250	83
34% - 100%	50	17
<i>Percentage of participant's work time spent at home</i>		
0 - 10%	259	86
> 10%	41	14
<i>Percentage of participant's work time spent in laboratories or workshops</i>		
0 - 10%	281	94
> 10%	19	6

Note: The three response options for time spent in regional, remote, or offshore locations (Section III Q34) were collapsed into two.

6.3.9.3. Participants' Work Time, Responsibility and Independence

Many of the surveyed established engineers worked under flexible conditions with only broad instructions, and frequently needed to learn new tasks. Most (64%) of the engineers in Survey 1 had regular flexible work schedules (Table 14). Most (84%) worked full-time and most (54%) worked to specific but flexible deadlines. Few (14%) received detailed instructions. Most (62%) needed to learn new tasks in their jobs at least monthly. These data suggest that engineers need to be self-motivated, able to work independently, responsible, and willing and able to learn.

Table 14. Participants' work contexts in Survey 1 of 300 established engineers: work time, responsibility, independence

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Nature of participant's work schedule</i>		
At discretion	58	20
Regular and flexible	185	64
Regular / Roster with paid overtime	29	10
Fly in – fly out	16	6
<i>Status of participant's current or most recent main engineering job</i>		
Full-time	253	84
Part-time	11	4
Self-employed / Proprietor / Director	20	7
Hourly contract employee	16	5
<i>Type of deadline that was covering the majority of the participant's work</i>		
Broad	60	20
Specific but flexible	161	54
Specific and strict	76	26
<i>Level of autonomy participant had in his/her work¹</i>		
Participant received few or no instructions	126	42
Participant received broad instructions	131	44
Participant received detailed instructions	43	14
<i>Result of participant performing job poorly²</i>		
0	14	5
Level 1: Loss of time / financial cost / loss of a client or project	160	53
Level 2: Lifestyle cost to society / cost to the economy / injury but not death for up to 5 people	37	12
Level 3: Local environmental cost / health cost or injury to more than 5 people	34	11
Level 4: Loss of human life / large-scale environmental cost	55	18
<i>Frequency with which participant needed to learn new tasks in his/her job</i>		
Annually	112	38
Monthly	153	51
Three or more times a month	34	11
<i>Percentage of participant's work time spent working alone (except perhaps communicating by email) in an average working day</i>		
0 – 33%	118	40
34% - 66%	117	39
67% - 100%	64	21

Notes:

- ^{1.} The five response options for the question about level of autonomy (Section III Q25) were collapsed into three options when the data were coded, to achieve sufficient responses within each category. The first two responses were combined and the last two responses were combined.

2. The question about consequence of error (Section III, Q30), asked “Which of the following would result if you performed your job poorly?” Respondents were asked to select all that applied among four options. Each response option described a worse result. This was coded on a five-point scale (0 = no option selected; Level 1 = first option only selected (*Loss of time / financial cost / loss of a client or project*); Level 2 = second option and not third or fourth option selected; Level 3 = third option and not fourth option selected; Level 4 = fourth option selected (*Loss of human life / large scale environmental cost*)).

6.3.9.4. Participants’ Work with Others

Trevelyan (2007) found that engineers spend much time coordinating the work of others without official authority over the people whose work they are coordinating. This could be the case for many of the established engineers in Survey 1. Most (76%) of the established engineers were responsible for fewer than ten people and most (74%) were directly supervising fewer than five people (Table 15). However, interaction with others was important. Only 24% of the established engineers communicated with fewer than six people on average per day, to achieve their work goals.

Communication is multidimensional. The engineers in Survey 1 communicated with people in diverse roles including engineers, people in trades, professionals, and community members - each of which would require different communication styles. However, most of the teams on which the majority (67%) of the engineers worked were not diverse with respect to women and cultural backgrounds. In addition to written and oral communication using words, engineers communicated spatial visual information, calculations and analysis.

**Table 15. Participants' work contexts in Survey 1 of 300 established engineers:
work with others**

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Number of people for whom participant was responsible (directly or indirectly)</i>		
0 to 9	227	76
10 to 19	29	10
> 19	44	15
<i>Number of people the participant was supervising directly</i>		
0 to 4	223	74
> 4	77	26
<i>Approximate number of people with whom participant communicated on average per day to achieve work goals</i>		
< 5	71	24
6 - 10	141	47
11 - 15	37	12
> 15	50	17
<i>People with whom participant had to communicate to achieve work goals</i>		
Technicians / tradespeople / labourers	148	49
Clients / users / lawyers / politicians / journalists	226	75
Community members	45	15
<i>Diversity groups represented in most of the teams in which participant was working¹</i>		
0	43	14
1	137	46
2	70	23
3 - 4	49	16
<i>Which types of communication was the participant using in his/her work²</i>		
Sketches / drawings / charts / diagrams/ graphs	211	70
Models / simulations / prototypes	115	38
Accounting/financial records	95	32
Calculations / analysis	163	54

Notes:

1. The diversity groups were: women, indigenous people, people working outside the country in which the participant was working, people who did most of their schooling outside the country in which the participant was based (Section III Q33). Participants selected all that applied.
2. Among the types of communication, obvious written and oral communication types were included in the questionnaire for comprehensiveness but are not included in the table.

6.3.10. Factors Related to Job Satisfaction of Participants in Survey 1

As a measure of job satisfaction, participants were asked to select all statements with which they agreed among six statements. Responses were coded by the number of statements selected.

Unlike the variables described above, this was included for validity purposes only. If the result had suggested that many of the participants felt negatively towards their jobs, then this could have biased the responses about important competencies. Fortunately, only 2% of participants selected none of the job satisfaction statements and the remaining participants were well-distributed among the levels of satisfaction (Table 16).

Table 16. Job satisfaction of participants in Survey 1 of 300 established engineers

<i>Variable and values</i>	<i>Responses</i>	<i>Responses as % of responses to question</i>
<i>Number of job satisfaction statements selected</i>		
0	5	2
1	33	11
2	27	9
3	40	13
4	50	17
5	63	21
6	82	27

Note: Participants were asked to select all statements with which they agreed, among the following:

- My work is valued in my organization.
- I influence decisions in my organization.
- My job provides me with professional development opportunities such as courses or conference leave.
- My organization provides me with challenge and opportunity to learn on the job.
- I have promotional opportunities in my organization.
- My job is secure (Section III, Q37).

6.4. Competency Gaps Identified by Open

Questions in Survey 1

The two brief open questions at the beginning of the questionnaire for Survey 1 identified perceived competency gaps. The primary purpose of this section of the questionnaire was to demonstrate to participants the subject of the survey, and that their expertise was required. The participants were asked about any competency gap that they had experienced when they graduated and any competency gap they had observed in recent graduates.

It can be assumed that engineers would name competency gaps only for competencies that they considered to be important. Therefore, the responses provided insight into the identification of competencies required by engineers graduating in Australia by identifying brief descriptions of competencies that individual engineers considered to be important. A journal paper (Male *et al.* 2010a), in which the responses to the two open questions were analysed, appears in Appendix XX. Dominant themes among the identified competency deficiencies were practical engineering, engineering business competencies, communication skills, self-management and appropriate attitude, problem-solving, and teamwork.

Practical engineering competency deficiencies included familiarity with sites, tools and methods, and also applications in common industries in which the engineers were employed, for example instrumentation and control, pumps, road and pit construction. “Design” featured among responses in the practical engineering theme.

Engineering business competency deficiencies included awareness of how engineering is done, for example the relationships between contractors, consultants and their clients. Engineering business competency deficiencies also included skills in engineering work such as planning, specification, estimation, project management, cost control, risk management and maintenance management. These examples explain the

comments received in the recent review of engineering education in Australia (Johnston *et al.* 2008), emphasising the need for engineering business competencies, rather than general business competencies only. This is a critical point which offers an opportunity for the engineering profession to enhance its identity. Engineering business competencies, in addition to the more readily recognised technical engineering competencies, distinguish professional engineers from other professionals.

6.5. *Ratings of Importance for the Competencies*

The Survey 1 and 2 ratings of importance for the competencies are shown in Appendix XXI. Analysis of the ratings from both surveys follows discussion of Survey 1 competency ratings.

6.5.1. Survey 1 Competency Ratings

Each competency was rated as critical by at least 14 (almost 5%) of the established engineers in Survey 1. All but three of the competency items were rated 3 or higher, on the scale from 1 to 5 (1 = *not needed*; 5 = *critical*), by at least half of the participants. As described in Chapter 3, the competencies had been identified to ensure that the final list of competencies, when combined with in-depth technical competence, was comprehensive with respect to competencies discovered to date. Therefore, the results of Survey 1 suggest that all of the competencies in the survey, when combined with in-depth technical competence, are the competencies that engineers graduating in Australia will require for their work as engineers.

The competencies identified include technical and non-technical items and encompass attitudes. Non-technical and attitudinal competencies were rated as important as technical competencies.

6.5.1.1. Competencies Rated as Critical by the Highest Numbers of Participants

The competency items rated as critical by the highest percentages of survey participants were consistent with literature on engineering education. They were *Communicating clearly and concisely in writing* (rated as critical by 62%), *Interacting with people in diverse disciplines/professions/trades* (58%), *Working in teams* (58%), *Managing self* (57%), *Solving problems* (56%), *Using effective verbal communication* (55%), *Managing own communications (e.g. keeping up to date and complete, following up)* (55%), *Speaking and writing fluent English* (54%), *Being committed to doing your best* (49%) and *Demonstrating honesty (e.g. admitting one's mistakes, giving directors bad news)* (49%).

6.5.1.2. Competencies Rated as Not Needed by the Highest Numbers of Participants

There are apparent inconsistencies between literature on engineering and higher education, and the competency items rated as not needed by the highest percentages of survey participants. The competency item rated as not needed by considerably more survey participants than any other item was *Working effectively in a second country*, which was not needed by 44% of the participants. This was followed by *Engaging in active citizenship* (28%), *Actively promoting diversity within your organization* (28%), *Evaluating / advocating for / improving manufacturability* (26%), *Using 3D spatial perception or visualization* (25%), and *Using research / experimentation techniques / scientific method* (21%). There were a further nine competencies rated as not needed by more than ten percent of the survey participants. Several of the competency items rated as not needed by relatively high percentages of participants, are competencies promoted in the literature.

6.5.1.2.1. *Citizenship*

While a desirable outcome of education, the results demonstrate that citizenship is not necessarily considered important by engineers to doing their jobs well. This is a competency that is relevant to the second part of Definition 1 for generic competencies for engineers defined in Chapter 1 (section 1.7.1.4.1). The second part of the definition refers to competencies that facilitate engineers' contributions to a well-functioning society. These competencies are necessary competencies but not necessarily identified by this study.

Although there is no doubt that citizenship is important, Survey 1 supported the explanation suggested by a member of the CEG Project Industry Advisory Committee, that engineering work is often performed in isolation from the community. In response to the question "Must you communicate with community members to achieve your work goals?" 85% of the participants selected *No* (Table 15).

6.5.1.2.2. *Working in a Second Country*

The high number of participants who saw no need to work effectively in a second country was consistent with the, previously noted, 71% of participants having worked in only one country during the two years prior to participation in the survey (Table 13).

In contrast, only 3% of Survey 1 participants rated *Interacting with people from diverse cultures/backgrounds* as not needed, and 33% rated this competency as critical. It was previously noted that over half of the participants in Survey 1 reported representation of fewer than two of the diversity groups (which were women, indigenous people, people working in another country, and people from another country) among most of the teams in which they were working (Table 15). The relatively high reported importance of *Interacting with people from diverse cultures/backgrounds* points to a different way of viewing the same data;

only 14% of participants had no members of diversity groups among most of the teams in which they were working.

6.5.1.2.3. Competencies Related to Diversity

Although *Interacting with people from diverse cultures/backgrounds* received relatively high ratings, *Actively promoting diversity within your organization (e.g. culture, religion)* did not. Based on the literature this result was unexpected.

By studying census and other data, Tilli and Trevelyan (in press) concluded that immigrants to Australia who gained their engineering qualifications overseas had lower rates of employment in engineering in Australia than engineers who trained in Australia. This suggests that promotion of diversity among the engineering workforce would help to address engineering skills shortages in Australia. Additionally, there is a large quantity of literature on improving recruitment and retention of women in engineering.

Despite the literature, 28% of the Survey 1 participants did not report it being necessary for them to actively promote diversity within their organizations in order to do their jobs well. Possible reasons for this include lack of awareness of links to business outcomes and lack of incentive, for individuals, such as identification and job performance indicators. It can be concluded that many participants distinguished between interacting with people from diverse backgrounds as important, and promoting diversity as not their responsibility.

6.5.1.2.4. Research, Experimentation and Scientific Method

Research, experimentation techniques and scientific method are listed in the EA Stage 1 Competencies (EA 2005a) and yet the results suggest that one fifth of engineers in the sample did not need to use these to do their jobs well.

This could be due to the industry representation in the sample. The survey was conducted from WA and 75% of participants worked mainly in WA (Table 7). The industries in which the highest percentages of participants were engaged were consulting/technical services, mining/quarrying, construction/contract/maintenance, and oil/gas exploration (Table 8). Management was the key responsibility most common among the participants, being selected by 59% of participants in Survey 1, while each other responsibility was selected by less than 40% (Table 9).

The explanation that local industry influenced the low importance ratings for *Research, experimentation techniques and scientific method* is supported by comparison of the percentages of participants with research and development as a key responsibility across participants working in Australia and those working overseas. Thirty-six Survey 1 participants were working outside Australia. Of these, all but two had gained their undergraduate engineering degrees in Australia. Therefore, 34 participants were engineers who had studied engineering in Australia and now worked overseas. Research, experimentation techniques and scientific method can be assumed to be required by engineers with research and development as a key responsibility. Research and development (including product design/development), was a key responsibility for 21% of participants working in Australia and 39% of those working overseas ($\chi^2(1) = 5.5$, $p = 0.02$) (Figure 3).

Figure 3. Survey 1 participants with and without research and development as a key responsibility, by country in which participant was working ($N = 300$)

The low ratings for research, experimentation and scientific method are significant because engineering science, and research and experimentation techniques, have been a main focus of engineering curricula, and a research project has been the focus of sought-after honours degrees. The survey results suggest that although scientific knowledge and research skills are important, they are not critical to all engineering jobs in local industry in WA. However, having scientific knowledge and research skills might contribute to other competencies such as critical thinking.

One of Trevelyan's (2007) findings from his ethnographic study of engineering practice is that engineers were using tacit knowledge and experience without realising. In contrast to the frequent low importance rating for *Using research / experimentation techniques / scientific method*, *Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in your discipline of engineering (e.g. ability to recognise unrealistic results)* was rated as critical by 46% of participants. In situations where engineers are using packages and products designed by others, or performing management roles, practical engineering knowledge is critical in order to recognise unrealistic results (His Excellency

Dr Ken Michael, AC, meeting with UWA Engineering Learning and Practice Research

Group, 7 June 2006). As noted, practical engineering was a theme among the competency gaps raised in responses to the two open questions in Survey 1. All of these findings are consistent with the high importance ratings for *Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in your discipline of engineering*.

The Royal Academy of Engineering study (Spinks *et al.* 2006) had a similar result, and its authors chose to emphasise a result that countered it. The relative importance of *Theoretical Understanding* was rated lower than *Practical Application*, consistent with the Survey 1 results. However, despite this outcome, participants indicated that *Theoretical Understanding* was regarded more highly when participants selected graduates for employment. *Theoretical Understanding* is a foundation necessary for *Practical Application*. As *Theoretical Understanding* has traditionally been a main construct represented on engineering academic records, employers could have been using this as an indicator for non-technical competencies such as *life-long learning, commitment, motivation and self-management*, which were important to engineers in the current study. This is suggested in a quotation from a qualitative part of the Royal Academy study:

A potential benefit of in-depth knowledge even after the specific domain had become obsolete was that it demonstrated, as one respondent put it, an “ability to master something difficult” (Spinks *et al.* 2006, p.21).

The low ratings for research, experimentation techniques and scientific method, despite the importance of practical engineering competencies, were further examined in the final focus group (Chapter 9).

6.5.1.2.5. Spatial Visualization

Three-dimensional spatial visualization and perception have been found to be correlated with success in engineering education programs, and courses have been developed to

improve spatial visualization skills in first year engineering students (Sorby and Baartmans 2000). However, one quarter of the established engineers who participated in Survey 1 rated use of spatial visualization and perception as not needed to do their jobs well. This could be because the engineering graduates have already been filtered and developed by engineering programs to include few people with difficulties with spatial visualization. In this case, the established engineers could be using spatial visualization without being aware of it because they are not having difficulties in the area. The result could also be a true reflection of one quarter of participants not needing spatial visulaization for their work.

In contrast, *Using effective graphical communication (e.g. reading drawings)*, was rated as critical by 41% of Survey 1 participants and rated 4 on the five-point scale (1 = *not needed*; 5 = *critical*) by a further 39%. This is even higher than expected based on the 70% of participants who reported using sketches, drawings, charts, diagrams or graphs in their work (Table 15).

6.5.1.2.6. Implications for the CEG Project

The low ratings for competencies that are promoted in the literature do not imply that these competency items should be excluded from engineering curricula or from an instrument to measure competencies of graduates for program evaluation and improvement. Each competency was rated as needed (a rating higher than 1) by a sufficient number of participants for all of the competencies to be considered generic for engineers graduating in Australia. Outcomes were confirmed by results of Survey 2 of senior engineers, as recommended for job analysis, and also finally by a focus group of people from engineering industries.

6.5.2. Importance Ratings for Each Competency, in Surveys 1 and 2

Visual inspection of the frequency distributions of the competency importance ratings made in Survey 2, by the senior engineers, and Survey 1, by the established engineers with five to twenty years' experience, revealed surprisingly similar patterns (Appendix XXI). No competency was rated as not needed by a higher percentage of participants in Survey 2 than in Survey 1. Therefore, in general the Survey 2 ratings did confirm the outcome of Survey 1, that the 64 competencies in the surveys are competencies required by engineers graduating in Australia.

Despite the similar patterns, the response distributions reveal a clear difference between the way that the established engineers in Survey 1 and the senior engineers in Survey 2 used the scale. For 55 of the 64 competencies, the senior engineers tended more than the established engineers to select one of the three inner points (2, 3 or 4) on the scale. The ratings for *networking* in Figure 4 demonstrate an example.

Figure 4. Distributions of ratings of importance of *networking* to doing an established engineering job well, in Survey 1 of 300 established engineers and Survey 2 of 250 senior engineers

Note: Distributions for all 64 competencies are presented in Appendix XXI. This figure is an example demonstrating the tendency for the senior engineers, more than the established engineers, to avoid the endpoints of the scale.

This avoidance of the endpoints could be due to greater conservatism in the senior engineers, which in turn, could be due to the difference between the questions asked of the two samples of engineers. The established engineers in Survey 1 were rating competencies on importance to performing their own jobs well. Therefore, they could confidently select 1 (*not needed*) or 5 (*critical*). The senior engineers were asked to rate the importance of the competencies for performing a specific typical established engineering job within their experience.

6.5.2.1. Mean Importance Ratings for Each Competency in Survey 1 and 2

There is approximate agreement between Surveys 1 and 2 on the mean importance ratings for each competency (Figure 5, Figure 6, Table 17). As noted in Chapter 5, the rating scale was designed with descriptors for the endpoints only, so that participants would mentally space the points on the scale evenly. Therefore, means were meaningful.

Appendix XXXII studies the differences between the Survey 1 and 2 ratings for individual competencies in greater detail. Analysis of the male engineers' competency ratings made in the two surveys revealed results consistent with gender typing of engineering jobs among the senior male engineers in the second survey. Gender typing is subconscious use of a gendered prototype of the ideal person for a job.

Appendix XXXII discusses the theory, analysis and implications.

Figure 5. Engineers' ratings of the importance of competencies to doing the jobs of established engineers well: competencies rated > 3.5 on average by established engineers

Notes:

- Missing values not imputed
- Survey 1 of 300 established engineers missed 0.2% of values
- Survey 2 of 250 senior engineers missed 0.3% of values
- Full competency names, as identified in the questionnaires, are in Table 17.

Figure 6. Engineers' ratings of the importance of competencies to doing the jobs of established engineers well: competencies rated < 3.5 on average by established engineers

Notes as for Figure 5

Table 17. Competency short and full names, ranked with descending mean importance rating in Survey 1

<i>Competency</i>	<i>Competency as identified in questionnaire</i>
Written comm.	Communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)
Managing comm.	Managing own communications (e.g. keeping up to date and complete, following up)
Self- management	Managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health)

Verbal comm.	Using effective verbal communication (e.g. giving instructions, asking for information, listening)
Teamwork	Working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)
English	Speaking and writing fluent English
Interdisc. skills	Interacting with people in diverse disciplines/professions/trades
Commitment	Being committed to doing your best
Problem-solving	Solving problems (e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs)
Honesty	Demonstrating honesty (e.g. admitting one's mistakes, giving directors bad news)
Decision-making	Making decisions within time and knowledge constraints
Self-motivation	Being positive/enthusiastic/motivated
Practical	Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in your discipline of engineering (e.g. ability to recognise unrealistic results)
Sourcing info	Sourcing/understanding/evaluating information (e.g. from co-workers/ colleagues/documents/observations)
Ethics	Acting within exemplary ethical standards
Demeanour	Presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)
Managing	Managing (e.g. projects/programs/ contracts/people/strategic planning/performance/change)
Critical thinking	Thinking critically to identify potential possibilities for improvements
Graphical comm.	Using effective graphical communication (e.g. reading drawings)
Flexibility	Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
Creativity	Thinking laterally / using creativity/initiative/ingenuity
Concern for others	Being concerned for the welfare of others in your organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution)
Negotiation	Negotiating / asserting/defending approaches/needs
Info-management	Managing information/documents
Action orientation	Having an action orientation (e.g. avoiding delays, maintaining a sense of urgency)
Coordinating	Coordinating the work of others
Meeting skills	Chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)
Loyalty	Being loyal to your organization (e.g. representing it positively)

Managing development	Managing personal and professional development (e.g. self-directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)
Presenting	Presenting clearly and engagingly (e.g. speaking, lecturing)
Diversity skills	Interacting with people from diverse cultures/backgrounds
Networking	Networking (i.e. building/maintaining personal/organizational networks)
Reliability	Evaluating reliability / potential failures
Design	Using design methodology (e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating)
Liability	Applying familiarity with risk/liability/legislation/standards/codes / IP issues
Leading	Leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)
Life-cycle	Being familiar with complete life-cycle of projects/programs/products
Supervising	Supervising work/people
Focus	Focusing on your organization's needs
Embracing change	Trying new approaches/technology / capitalising on change / initiating/driving change
Cross-fn familiarity	Applying familiarity with the different functions in your organization and how these interrelate
Mentoring	Mentoring/coaching co-workers
Maintainability	Evaluating / advocating for / improving maintainability
Risk-taking	Taking considered risks
Keeping up to date	Keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials
Theory	Applying mathematics, science or technical engineering theory or working from first principles
Workplace politics	Understanding social and political dimensions of workplaces
Safety	Evaluating / advocating for / improving health and safety issues
Community	Being concerned for the welfare of the local, national and global communities
Generalisation	Generalising/abstracting concepts
Systems	Using a systems approach
Sustainability	Evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions
Modelling	Modelling/simulating/prototyping and recognising the limitations involved
Integrated design	Using “simultaneous engineering design and development” / “integrated product and process design” / “collaborative engineering”
Marketing	Evaluating marketing issues / applying a customer focus

Aesthetics	Appreciating aesthetic features of design
Social context	Evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)
Entrepreneurship	Engaging in entrepreneurship / innovation / identifying and commercialising opportunities
3D skills	Using 3D spatial perception or visualization (e.g. visualizing various perspectives)
Research	Using research / experimentation techniques / scientific method
Manufacturability	Evaluating / advocating for / improving manufacturability
Promoting diversity	Actively promoting diversity within your organization (e.g. culture, religion)
Citizenship	Engaging in active citizenship (e.g. being involved in the local / national or international community / engaging in public debates)
Working internationally	Working effectively in a second country

Note: This table is provided for ready access to the full names of the competencies shown in Figure 5 and Figure 6.

The mean ratings reveal additional competencies that have low ratings despite popularity in the literature. Relatively low mean ratings were received for *sustainability: Evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions* and *social context: Evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)*. These are similar to the EA generic graduate attributes (2005b) *Understanding of the principles of sustainable design and development* and *Understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development*, required for program accreditation in Australia.

Competencies related to social, cultural, global, environmental, and sustainability responsibilities are frequently promoted in engineering education literature (for example, Froyd 2005) and initiatives have been taken to develop engineering students' competencies in these areas (for example, Engineers Without Borders Australia 2006).

Low mean ratings of the *sustainability* and *social context* competencies are consistent with responses to the task inventory in Survey 1. Participants were asked to “Select the tasks that you must do to do your current job well.” and of the five environmental management tasks, which included two relating to sustainable development, 57% of the participants selected none, 23% selected one or two and only 20% selected more than two (Table 10).

Chapter 1 discussed how it would have been ideal to focus on generic engineering competencies for work and society (Definition 1) but it was necessary to focus on generic engineering competencies for work and incidentally for society (Definition 2). Awareness of this limitation is important when considering ratings for competencies related to sustainability and social context. Regardless of any low ratings obtained in this study due to its focus on work and only incidentally society, giving priority for sustainability and the social context of engineering are competencies that are unquestionable. Putting the community first is the first item in the first tenet of the *Code of Ethics of the Institution of Engineers, Australia*:

Members shall place their responsibility for the welfare, health and safety of the community before their responsibility to sectional or private interests, or to other members (IEAust 2000, p.2).

The draft *Code of Ethics for the Review of the Code of Ethics – 2010* now includes sustainability. The first value to which members should be committed is “Public wellbeing, health and safety and sustainability” (IEAust 2009).

6.6. Comments from Senior Engineers in Survey 2

Valuable comments were provided by senior engineers. Five recommended additional competencies related to business skills. These included focusing on clients’ needs, costing, financial management, quality control, business management and risk

management. The questionnaires included competencies related to these but not specifically focusing on these competencies alone. One senior engineer sensibly recommended that the *manufacturability* competency be amended to relate to *constructability/manufacturability*.

6.7. Implications for the Research Questions

The first main research question was:

What are the generic engineering competencies that engineers graduating in Australia require for their work as engineers?

The survey results imply that all of the 64 competencies identified from the literature, in addition to in-depth technical knowledge in at least one engineering discipline, are required by engineers graduating in Australia. The Survey 2 comments suggest that additional items related to costing, financial management, quality control, business management and risk management could be required. This is considered in the final focus group (Chapter 9).

The competencies were mapped conceptually to the EA generic graduate attributes for easy comparison (Figure 7).

Figure 7. Engineers' importance ratings for competencies in Survey 1 of established engineers ($N = 300$), mapped conceptually to EA graduate attributes

The first research sub-question was:

Are the engineering program outcomes currently required for accreditation in Australia aligned with the identified generic engineering competencies?

There were four competency items identified among the 64 competencies and not clearly included in the EA generic graduates attributes. *Cross-function familiarity*, *workplace politics*, *entrepreneurship* and *marketing* are competencies that engineers need in their work, as demonstrated by the survey results, and that are not represented by the EA generic graduate attributes. Of these, Ferguson (2006a) identified *entrepreneurship* and implicitly identified *marketing* as items that need to be added to the accreditation requirements. The results indicate that the EA graduate attributes are well aligned with the competencies required by engineers graduating in Australia, and that the EA graduate attributes are necessary but not sufficient to develop all of the competencies required. Therefore, changes driven by the accreditation criteria are further supported by this study, and measurement of the competencies identified in this study would assist program evaluation and improvement.

6.8. Implications for Competency Theory

The surveys revealed the alignment of the required competencies and the EA accreditation requirements. They also highlighted priorities. Basic science and engineering fundamentals and competencies related to society, the environment, and sustainability are among the EA graduate attributes. However, they were rated as less important for work than other competencies. As discussed, the survey data suggested that the relatively low ratings for these competencies could be due to the nature of the work performed by engineers in WA.

However, the theoretical framework provides an additional possible explanation. The framework, introduced in Chapter 1, emphasised the importance of the purpose for

which competencies are selected, and the stakeholders for whom they are selected. An explanation for the apparent inconsistencies between priorities in the engineers' ratings of importance for the competencies and those listed in accreditation requirements, is the different purposes for which the competencies were rated in the survey and for which program outcomes are identified for accreditation. The EA attributes are designed to protect society. They ensure that graduating engineers have the foundation competencies for this purpose. The current study identified competencies needed by established engineers for their engineering work. These competencies can be assumed to satisfy the engineers' organizations and, as discussed (section 1.7.1.4.1), should therefore satisfy society. Therefore, the EA graduate attributes and the generic competencies identified in this study were identified to satisfy different stakeholders. The theoretical framework therefore provides an explanation for the apparent inconsistency between the survey data and the literature.

6.9. Conclusion

This chapter presents results of Surveys 1 and 2. The individual competency ratings on importance were analysed. Although some competencies received relatively low mean ratings, all 64 competencies were rated as needed by a sufficient number of engineers to indicate that they are generic engineering competencies for engineers graduating in Australia. With a small number of additions, the EA graduate attributes, required for engineering education program accreditation, are consistent with the results.

CHAPTER 7. Identification of Competency Factors

7.1. Introduction

The development of a practical survey tool for assessing graduates will require a short yet comprehensive list of competency groupings or “factors”. As described in earlier chapters, 64 competencies were identified as important. Chapter 6 presented results and analysis of the ratings for the individual competencies. The large number of competencies is now grouped into a smaller list of factors based on the competency ratings. The factors are more suitable for survey applications in program evaluation than the long list of competencies. The factors also simplify comparison of the importance of competencies across sample groups, representing different personal characteristics and engineering jobs.

This chapter addresses the second main research question:

What are the generic engineering competency factors required by engineers graduating in Australia?

7.1.1. Significance

The competency factors could later be used to develop an instrument to measure the competencies of engineering graduates using ratings made by supervisors of graduates.

Namely:

1. Competency factors could be used to reduce the number of competencies rated by supervisors, because a whole competency factor could be avoided if it is not relevant to the graduate’s job.

2. Scores for competency factors based on supervisors' overall ratings of the competencies in that factor, could provide simpler representations of graduates' competencies, than would ratings on 64 individual competencies.

7.1.2. Background

Program outcomes have been stipulated by organizations that accredit engineering programs and thereby drive improvement of engineering programs. Outcomes stipulated by ABET (USA), the European Network for Accreditation of Engineering Education (ENAE) and EA are similar in content, yet each groups the outcomes slightly differently. EA stipulates ten graduate attributes, which are similar to the eleven program outcomes stipulated by ABET.

Approximately half of the EA attributes and ABET outcomes are non-technical. In contrast, by means of the grouping of program outcomes, the ENAE has operationalised technical items at a higher level of specificity than has EA or ABET. Five of the six program outcomes stipulated by the ENAE are largely technical.

Creativity is explicitly noted among these, although not by EA or ABET. The non-technical items listed separately by EA and ABET are included in the ENAE outcome *Transferable Skills* (European Network for Accreditation of Engineering Education 2008). Business skills and project management appear in the ENAE *Transferable Skills* and also in the EA Stage 1 Competencies (EA 2005a). There was, therefore, a need for consensus in the grouping of competencies. An empirically identified factor structure among the competencies required by engineers graduating in Australia would contribute to the development of such consensus.

7.1.3. Methodology

Within the theoretical framework adapted from the DeSeCo Project (OECD 2003) introduced in Chapter 1, competencies exist in constellations and are observed as

responses to demands in context. This has been adapted in this Project to mean that manifestations of the competencies required by engineers can be observed as responses to demands and contexts imposed by engineers' jobs.

The surveys in this Project collected ratings of the importance of competencies for individual jobs. Based on the viewpoint that the required competencies are determined by the nature of the engineering job, correlations between competency ratings were expected to be due to similarities in demands or contexts imposed by jobs. Provided that the data meet required conditions discussed below, factor analysis reveals correlated groups of variables. Therefore, factor analysis of the importance ratings for the competencies was used to identify competency factors arising from job characteristics.

Appendix XXIII provides an overview of factor analysis. The purpose of the study influenced the choice of extraction method used to identify factors. The theoretical understanding of competencies influenced the choice of rotation method. This is discussed below.

7.2. Method

Survey 1 had asked engineers to rate the importance of competencies for their own jobs. This chapter focuses on an exploratory factor analysis of the competency importance ratings, from Survey 1, to reveal latent competency factors reflected by groups of competencies with similar importance ratings.

Principal axis factoring, also known as “principal factors”, was used because it is more robust to non-normality than the maximum likelihood extraction method (Floyd and Widaman 1995, Fabrigar *et al.* 1999).

An oblique (direct oblimin) rotation was performed, rather than an orthogonal rotation which would have forced the factors to be uncorrelated. The SPSSTM default delta parameter ($\delta = 0$), which controls the level of correlation between factors, was used.

The pattern matrix which defines the oblique factors in terms of the reflecting variables was used to identify the variables allocated to each factor.

Although it was considered appropriate for factors to be oblique, it would be unhelpful for applications of the factors, if the allocation of variables was confusing. Therefore, discriminant validity of the factor structure was sought. To finally test and refine the discriminant validity of the preferred factor structure, the structure matrix was used because this matrix shows the correlation between factors and all of the variables reflecting the factors.

7.3. Results of Factor Analysis

7.3.1. Survey 1 Competency Factor Structure with All 64 Variables

An exploratory factor analysis, using principal axis factoring, was carried out on the competency ratings in Survey 1 using SPSSTM 17.0 2008. The syntax is provided in Appendix XXIV.

The scree test is a method for determining the number of meaningful factors in data (Cattell 1966, Cattell and Vogelmann 1977). The test is performed by counting the number of factors before a corner, or elbow, in the scree plot of eigenvalues for each factor. The scree test for the competency ratings from Survey 1 suggested that two, nine or eleven factors should be extracted (Figure 8). The Kaiser Guttman test, which is an alternative to the scree test, recommends including the factors with eigenvalues greater than one (Hoyle and Duvall 2004). Fabrigar (1999) argues and Russell (2002) agrees that this test selects too many factors. It would have recommended 15 factors. Structures with 2, 3, 6, 9, 10, 11, 12, 13, 14, or 15 factors were compared conceptually as recommended by Meyers *et al.* (2006), and eleven was selected as the most appropriate number of factors.

Note: Elbows at 3rd, 10th and 12th factors suggest 2, 9 or 11 factors

Figure 8. Scree plot from Survey 1 competency importance ratings (64 competencies) ($N = 300$)

The Pearson r bivariate correlations ranged in magnitude from less than 0.01 to a maximum value of 0.68, and 86% of the correlations were significant ($p < 0.05$), suggesting suitable correlations for factor analysis. Kaiser's measure of sampling adequacy (0.89) was consistent with suitability of the data for factor analysis. Bartlett's test of sphericity was significant and therefore satisfactory ($\chi^2(2016) = 8854$, $p < 0.001$). Most off-diagonal elements of the anti-image correlation matrix had magnitudes less than 0.1, satisfying the requirement that they be mostly small. However, 38 elements had magnitudes above 0.2, four of which were above 0.3, and two above 0.4. The maximum communality after the extraction was 0.7 (Table 18).

Eleven initial factors (as would be explained by principal components analysis)

explained 56% of the total variance. The factors extracted using principal axis factoring

explained 48% of the total variance.

Table 18. Communalities for competency importance ratings from established engineers in Survey 1 ($N = 300$) for unrotated factor analysis extracted using principal axis factoring and 11 factors

<i>Competency</i>	<i>Communalities</i>	
	<i>Initial</i>	<i>Extracted</i>
Diversity skills	0.45	0.44
Interdisc. skills	0.46	0.38
Mentoring	0.42	0.28
Teamwork	0.49	0.45
Written comm.	0.49	0.47
Managing comm.	0.44	0.37
Negotiation	0.52	0.43
Presenting	0.54	0.54
English	0.43	0.37
Graphical comm.	0.44	0.40
Verbal comm.	0.51	0.40
Working internat.	0.36	0.23
Theory	0.51	0.51
Aesthetics	0.43	0.35
Life-cycle	0.48	0.37
Practical	0.49	0.41
Maintainability	0.61	0.62
Manufacturability	0.52	0.46
Sustainability	0.68	0.68
Reliability	0.49	0.41
Social context	0.64	0.59
Generalisation	0.52	0.44
Modelling	0.57	0.47
Problem-solving	0.48	0.38
Sourcing info	0.57	0.60
Critical thinking	0.56	0.55
Creativity	0.63	0.58
Embracing change	0.64	0.60
Integrated design	0.53	0.53
3D skills	0.50	0.46
Systems	0.51	0.39
Design	0.49	0.40
Research	0.57	0.51
Promoting diversity	0.53	0.48
Liability	0.49	0.42
Cross-fn familiarity	0.52	0.46
Flexibility	0.52	0.43
Meeting skills	0.57	0.52

Coordinating	0.61	0.57
Entrepreneurship	0.55	0.52
Marketing	0.46	0.37
Safety	0.59	0.51
Focus	0.52	0.43
Leading	0.65	0.62
Decision-making	0.50	0.44
Managing	0.54	0.49
Networking	0.53	0.43
Supervising	0.63	0.58
Risk-taking	0.57	0.51
Workplace politics	0.54	0.46
Self-motivation	0.49	0.41
Citizenship	0.54	0.46
Action orientation	0.49	0.40
Keeping up to date	0.58	0.50
Info-management	0.47	0.40
Managing development	0.47	0.49
Self-management	0.48	0.42
Ethics	0.56	0.55
Commitment	0.60	0.55
Concern for others	0.61	0.52
Community	0.70	0.70
Loyalty	0.63	0.64
Honesty	0.61	0.61
Demeanour	0.53	0.48

Note: The competencies are identified by their short names. The full names are listed in the same order in Table 1.

The pattern matrix resulting from the factor analysis of all 64 variables revealed eleven factors representing groups of competencies that were needed in similar engineering jobs (Table 19). The factors made sense conceptually and were named based on the variables reflecting them (Table 20). The highest magnitude of a correlation between factors was 0.37 (Table 21).

Table 19. Pattern matrix from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), analysed using principal axis factoring, direct oblimin rotation, 11 factors, and all 64 competencies

Competency	Factor										
	1	2	3	4	5	6	7	8	9	10	11
Supervising	0.73	0.05	0.02	0.03	0.01	0.02	0.08	0.10	-0.09	0.10	0.07
Coordinating	0.68	0.08	0.16	0.00	0.03	0.02	-0.03	-0.11	0.03	-0.03	0.07
Leading	0.66	-0.02	0.00	-0.17	0.02	-0.05	-0.09	0.16	0.13	-0.13	-0.05
Managing	0.65	-0.03	0.06	0.01	-0.09	0.07	-0.03	-0.04	0.02	0.00	0.05
Risk-taking	0.51	-0.08	-0.16	0.03	0.15	0.13	0.01	0.20	0.10	0.16	-0.08
Decision-making	0.45	0.05	0.05	-0.03	0.00	-0.04	-0.10	-0.16	0.15	0.23	0.00
Meeting skills	0.43	-0.16	0.10	-0.07	-0.13	0.08	-0.26	-0.05	0.20	-0.08	0.07
Workplace politics	0.35	0.00	-0.17	0.03	-0.07	0.23	-0.06	0.23	0.13	0.17	0.02
Focus	0.33	-0.10	-0.12	-0.18	0.03	0.08	-0.12	0.07	0.22	0.03	0.05
Mentoring	0.32	-0.07	-0.06	-0.09	0.17	-0.07	0.06	0.13	0.04	0.09	0.14
Theory	-0.10	0.63	0.09	-0.04	0.03	0.02	-0.01	0.02	0.09	0.07	0.04
3D skills	0.17	0.60	-0.03	-0.06	0.06	0.10	-0.08	-0.04	-0.02	-0.02	0.04
Modelling	-0.17	0.51	-0.04	0.08	-0.02	0.02	-0.27	0.08	0.07	0.08	0.00
Research	-0.18	0.39	0.04	0.04	-0.03	0.23	-0.24	0.28	-0.05	0.05	0.09
Aesthetics	0.00	0.35	0.15	0.00	0.32	0.02	0.16	0.14	0.08	0.01	-0.02
Design	-0.08	0.25	-0.14	-0.12	0.20	0.00	-0.25	-0.19	0.08	0.20	0.08
Graphical comm.	0.14	0.17	0.54	0.03	0.16	0.05	-0.03	-0.06	-0.15	-0.02	-0.02
English	-0.03	-0.08	0.51	-0.17	-0.10	0.02	-0.15	0.07	-0.03	0.03	-0.03
Written comm.	-0.08	0.13	0.50	-0.02	-0.09	0.09	0.00	0.09	0.20	0.20	-0.07
Verbal comm.	0.13	-0.09	0.44	-0.06	0.04	0.02	-0.14	0.01	0.08	0.08	0.05
Presenting	0.00	-0.16	0.35	-0.03	-0.08	0.06	-0.19	0.34	0.04	0.07	0.28
Negotiation	0.19	-0.23	0.24	0.05	0.07	0.14	-0.17	0.16	0.17	0.11	0.04
Honesty	-0.02	0.00	0.02	-0.77	-0.01	-0.05	0.00	0.10	0.09	-0.05	-0.01
Loyalty	0.01	0.06	0.04	-0.76	0.09	-0.11	0.03	0.09	0.05	0.02	-0.01
Commitment	0.06	0.01	0.05	-0.61	-0.02	0.13	-0.10	-0.11	-0.09	0.10	0.06
Ethics	-0.09	0.05	0.02	-0.56	-0.07	0.36	0.01	-0.14	0.06	0.02	0.06
Demeanour	-0.02	0.00	0.05	-0.49	-0.03	-0.09	0.08	0.10	0.08	0.23	0.18
Concern for others	0.21	-0.05	-0.05	-0.45	0.09	0.29	-0.12	-0.08	-0.03	0.11	-0.17
Self-motivation	0.01	-0.19	0.12	-0.37	0.08	-0.01	0.03	0.04	-0.14	0.21	0.25
Maintainability	-0.02	-0.18	-0.01	0.00	0.72	0.20	-0.16	-0.07	0.05	-0.05	-0.03
Manufacturability	0.02	0.26	-0.02	-0.04	0.51	0.08	0.02	0.05	-0.15	-0.03	0.13
Reliability	-0.05	0.09	0.05	-0.05	0.49	0.17	-0.10	-0.07	0.11	0.00	-0.06
Integrated design	0.07	0.36	-0.03	-0.06	0.44	0.00	-0.15	0.11	-0.09	-0.02	0.07
Practical	0.09	0.24	0.20	-0.05	0.26	-0.13	-0.09	-0.06	0.18	0.20	-0.19
Sustainability	0.02	-0.02	0.18	0.03	0.26	0.67	-0.04	-0.10	0.08	-0.09	0.06
Social context	0.03	0.08	0.11	0.14	0.14	0.65	0.09	0.08	0.10	0.08	0.08
Community	0.00	0.11	-0.03	-0.29	0.05	0.62	-0.04	0.06	0.03	0.08	-0.06
Safety	0.25	-0.12	0.01	-0.15	0.20	0.44	0.02	-0.08	0.14	-0.10	0.03

Citizenship	0.02	0.09	0.00	-0.13	-0.04	0.42	0.00	0.29	-0.03	0.16	0.03
Promoting diversity	0.07	0.05	-0.27	-0.07	-0.07	0.38	0.02	0.11	0.06	0.11	0.31
Critical thinking	0.05	0.02	0.09	-0.02	0.06	0.01	-0.70	-0.06	-0.10	0.02	0.04
Sourcing info	0.06	0.06	0.14	0.07	0.00	-0.02	-0.66	-0.16	0.03	0.13	0.03
Creativity	0.07	0.10	0.04	-0.12	-0.01	-0.05	-0.60	0.17	0.01	-0.05	0.14
Embracing change	-0.08	-0.03	-0.05	-0.09	0.27	0.04	-0.56	0.29	0.01	0.00	-0.04
Problem-solving	-0.03	0.14	0.11	0.02	0.07	0.00	-0.45	-0.04	0.11	0.09	0.00
Flexibility	0.07	-0.14	0.01	-0.02	0.01	-0.07	-0.36	0.11	0.34	0.12	0.04
Systems	0.09	0.21	-0.10	-0.04	0.22	-0.06	-0.26	0.15	0.09	0.06	0.11
Entrepreneurship	0.20	0.20	0.05	-0.11	-0.03	0.04	-0.08	0.50	0.07	-0.14	0.10
Marketing	0.20	0.03	0.05	-0.11	0.01	0.04	0.00	0.47	-0.03	-0.03	0.06
Keeping up to date	-0.10	0.11	-0.01	-0.12	-0.04	0.23	-0.08	0.37	0.03	0.31	0.00
Networking	0.34	-0.07	0.02	-0.02	-0.10	0.06	-0.01	0.35	0.02	0.11	0.16
Liability	0.05	0.12	0.10	-0.07	-0.03	0.15	0.11	-0.15	0.54	-0.01	0.06
Cross-fn familiarity	0.18	-0.03	-0.12	-0.06	-0.02	0.13	-0.05	0.00	0.49	-0.02	0.12
Life-cycle	0.00	0.00	-0.07	-0.05	0.31	-0.07	0.00	0.05	0.37	0.06	0.17
Generalisation	-0.04	0.24	-0.04	-0.05	0.05	0.06	-0.21	0.30	0.33	-0.05	-0.10
Managing development	0.07	-0.04	-0.04	-0.16	-0.01	0.14	-0.08	0.00	-0.08	0.57	-0.03
Self-management	0.05	0.08	0.03	-0.28	-0.06	-0.05	-0.05	-0.12	0.04	0.45	-0.02
Info-management	0.10	0.21	0.21	-0.02	-0.06	0.01	-0.02	-0.07	0.05	0.43	0.04
Managing comm.	-0.07	-0.10	0.26	0.03	0.01	0.04	-0.07	0.13	0.18	0.35	0.06
Action orientation	0.19	-0.09	-0.05	-0.16	0.05	-0.01	-0.16	0.03	0.01	0.32	0.14
Diversity skills	0.02	0.10	-0.07	-0.02	-0.09	0.08	-0.19	-0.03	0.06	-0.02	0.57
Interdisc. skills	0.13	-0.06	0.30	-0.08	0.03	0.07	0.01	-0.11	0.12	-0.11	0.37
Teamwork	0.17	-0.12	0.09	0.05	0.25	-0.08	-0.04	-0.21	0.14	0.22	0.33
Working internat.	-0.05	0.11	-0.06	-0.09	0.12	-0.02	0.06	0.21	0.02	0.00	0.31

Notes:

- Shading indicates competencies reflecting factors.
- Full names for the competencies are listed in Table 17.

Table 20. Factors identified using factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), analysed using principal axis factoring, direct oblimin rotation, 11 factors, and all 64 competencies

<i>Factor number</i>	<i>Factor name</i>	<i>Competencies reflecting factor</i>
1	Management/Leadership	Supervising, Coordinating, Leading, Managing, Risk-taking, Decision-making, Meeting skills, Workplace politics, Focus, Mentoring
2	Applying Technical Theory	Theory, 3D skills, Modelling, Research, Aesthetics, Design
3	Communication	Graphical comm., English, Written comm.,

		Verbal comm., Presenting, Negotiation
4	Professionalism	Honesty, Loyalty, Commitment, Ethics, Demeanour, Concern for others, Self-motivation
5	Practical Engineering	Maintainability, Manufacturability, Reliability, Integrated design, Practical
6	Contextual Responsibilities	Sustainability, Social context, Community, Safety, Citizenship, Promoting diversity
7	Creativity / Problem-Solving	Critical thinking, Sourcing info, Creativity, Embracing change, Problem-solving, Flexibility, Systems
8	Innovation	Entrepreneurship, Marketing, Keeping up to date, Networking
9	Engineering Business	Liability, Cross-fn familiarity, Life-cycle, Generalisation
10	Self-management	Managing development, Self-management, Info-management, Managing comm. Action orientation
11	Working in Diverse Teams	Diversity skills, Interdisc. skills, Teamwork, Working internat.

Table 21. Factor correlation matrix from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), using principal axis factoring, direct oblimin rotation, 11 factors, and all 64 competencies

<i>Factor</i>	1	2	3	4	5	6	7	8	9	10	11
1	1.00	-0.14	0.14	-0.26	0.15	0.23	-0.19	0.13	0.31	0.20	0.30
2		1.00	0.06	-0.07	0.28	0.14	-0.19	0.14	0.09	0.12	0.03
3			1.00	-0.11	0.07	0.09	-0.21	-0.04	0.15	0.21	0.08
4				1.00	-0.15	-0.28	0.24	-0.18	-0.21	-0.37	-0.29
5					1.00	0.18	-0.20	0.04	0.20	0.09	0.15
6						1.00	-0.18	0.17	0.24	0.16	0.18
7							1.00	-0.16	-0.28	-0.32	-0.17
8								1.00	0.10	0.11	0.21
9									1.00	0.26	0.23
10										1.00	0.20
11											1.00

Note: Shading indicates values with the highest magnitudes.

As discussed in Appendix XXIII, MacCallum *et al.* (1999) demonstrated that the number of responses required for factor analysis is influenced, not only by the number

of factors, but also by the communalities of the indicators, or competency variables in this case, and whether there are sufficient indicators per factor. The necessary number of responses decreases if the number of factors is low, the number of indicators per factor is higher than three or four, and the communalities are high.

All of the initial communalities for competency importance ratings from Survey 1, except *working internationally*, were greater than 0.4 (Table 18). The factor structure with eleven factors had two factors reflected by only four indicators and one factor reflected by only three indicators, but all of the other eight factors were reflected by five or more indicators (Table 20). Therefore, it was expected that the sample for Survey 1 ($N = 300$) should be large enough for factor analysis.

Tabachnick and Fidell (p.622) recommend that the correlation residuals should be mostly less than 0.05 and none above 0.1. Most of the residual correlations in this analysis were less than 0.05, although the two highest magnitudes were 0.10 and 0.14.

7.3.2. Refined Factor Structure

We now focus on the factor structure of the competency ratings from Survey 1. The structure was refined by removing competencies until a structure with clearly differentiated factors was identified. As noted in Appendix XXIII, there are various recommendations about whether the pattern or structure matrix should inform refinement of the factor structure. Table 22 is the structure matrix resulting from factor analysis of the ratings for all 64 competencies. Its elements, also called structure coefficients, are the correlations between the competencies and the factors.

For the Survey 1 competency ratings, the pattern and structure matrices identified a similar set of eleven factors. However, the competencies *design*, *presenting*, *negotiation*, and *networking*, reflect different factors in the structures indicated by the pattern matrix and the structure matrix. For example, based on the pattern matrix, *presenting* and *negotiation* reflect the Communication Factor. However, based on the

structure matrix, *presenting* reflects the Working in Diverse Teams Factor, and *negotiation* reflects the Management/Leadership Factor. As noted by Brown (2006), these small differences between the factor structures identified by the pattern and structure matrices were not problematic because the variables affected were unlikely to be in the refined factor structure. They did not clearly reflect one factor better than another. Therefore, despite the minor differences between the structure and pattern matrices, the structure matrix was used for the process of refining the factor structure.

The structure matrix (Table 22) revealed that discriminant validity was not achieved in the eleven-factor structure for the competency ratings with all 64 variables. For example, based on the structure matrix, *safety* reflects factor 6, and yet it is more strongly correlated with factor 1 than is *mentoring* or *negotiation*, which reflect factor 1 in the factor model. The factors would be more useful for future studies if they were clearly separate factors representing separate groups of competencies needed by similar jobs.

Table 22. Structure matrix from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), analysed using principal axis factoring, direct oblimin rotation, 11 factors, and all 64 competencies

Competency	Factor										
	1	2	3	4	5	6	7	8	9	10	11
Supervising	0.74	-0.04	0.12	-0.20	0.12	0.20	-0.11	0.20	0.17	0.23	0.29
Leading	0.73	-0.07	0.11	-0.34	0.16	0.19	-0.26	0.27	0.35	0.12	0.23
Coordinating	0.72	0.00	0.28	-0.21	0.19	0.21	-0.21	0.01	0.28	0.17	0.28
Managing	0.69	-0.13	0.16	-0.19	0.03	0.21	-0.16	0.07	0.24	0.16	0.25
Risk-taking	0.61	-0.05	-0.04	-0.23	0.24	0.31	-0.19	0.30	0.32	0.27	0.19
Meeting skills	0.59	-0.18	0.23	-0.27	0.02	0.24	-0.37	0.07	0.41	0.18	0.28
Decision-making	0.54	0.02	0.21	-0.25	0.15	0.15	-0.29	-0.04	0.37	0.39	0.20
Focus	0.51	-0.06	0.02	-0.38	0.17	0.28	-0.30	0.21	0.42	0.26	0.29
Workplace politics	0.49	0.03	-0.05	-0.25	0.08	0.39	-0.24	0.37	0.34	0.31	0.26
Networking	0.48	-0.07	0.09	-0.26	0.01	0.23	-0.19	0.44	0.23	0.26	0.36
Mentoring	0.43	-0.05	0.02	-0.25	0.22	0.10	-0.10	0.21	0.21	0.20	0.31

Negotiation	0.42	-0.13	0.34	-0.21	0.16	0.29	-0.35	0.23	0.38	0.30	0.25
Theory	-0.09	0.68	0.16	-0.15	0.24	0.16	-0.21	0.13	0.18	0.20	0.10
3D skills	0.14	0.61	0.06	-0.19	0.29	0.25	-0.25	0.12	0.15	0.14	0.14
Modelling	-0.16	0.60	0.04	-0.04	0.17	0.12	-0.37	0.18	0.14	0.19	0.03
Research	-0.09	0.53	0.10	-0.15	0.16	0.34	-0.38	0.40	0.11	0.20	0.17
Aesthetics	0.03	0.45	0.17	-0.10	0.42	0.15	-0.05	0.18	0.17	0.10	0.08
Written comm.	0.07	0.22	0.56	-0.19	0.04	0.21	-0.24	0.12	0.32	0.37	0.06
Graphical comm.	0.16	0.22	0.56	-0.07	0.25	0.13	-0.17	-0.05	0.02	0.11	0.05
English	0.11	-0.02	0.54	-0.25	-0.04	0.11	-0.26	0.08	0.10	0.22	0.07
Verbal comm.	0.31	-0.02	0.53	-0.24	0.14	0.17	-0.32	0.06	0.27	0.29	0.21
Loyalty	0.21	0.14	0.13	-0.78	0.21	0.16	-0.21	0.23	0.22	0.32	0.24
Honesty	0.20	0.06	0.10	-0.77	0.11	0.19	-0.20	0.23	0.23	0.26	0.23
Commitment	0.26	0.07	0.17	-0.70	0.12	0.32	-0.29	0.06	0.15	0.38	0.27
Ethics	0.13	0.12	0.12	-0.64	0.09	<u>0.49</u>	-0.17	0.03	0.22	0.27	0.23
Demeanour	0.21	0.06	0.15	-0.61	0.08	0.13	-0.17	0.22	0.25	0.44	0.36
Concern for others	0.37	0.03	0.09	-0.58	0.22	0.45	-0.30	0.07	0.22	0.34	0.10
Self-motivation	0.24	-0.12	0.20	-0.50	0.12	0.15	-0.14	0.14	0.07	0.37	0.39
Maintainability	0.17	0.07	0.07	-0.15	0.73	0.31	-0.28	-0.02	0.23	0.07	0.11
Manufacturability	0.08	0.41	0.02	-0.16	0.59	0.21	-0.14	0.14	0.03	0.06	0.22
Integrated design	0.13	<u>0.51</u>	0.05	-0.21	0.58	0.19	-0.32	0.22	0.12	0.14	0.20
Reliability	0.09	0.28	0.14	-0.18	0.57	0.29	-0.27	0.00	0.26	0.14	0.07
Practical	0.15	0.34	0.31	-0.18	0.38	0.05	-0.31	-0.01	0.31	0.34	-0.04
Community	0.23	0.25	0.09	<u>-0.51</u>	0.24	0.75	-0.28	0.24	0.28	0.31	0.19
Sustainability	0.25	0.14	0.27	-0.22	0.41	0.74	-0.23	0.03	0.31	0.10	0.22
Social context	0.23	0.22	0.19	-0.15	0.29	0.71	-0.14	0.20	0.30	0.20	0.24
Safety	<u>0.45</u>	-0.04	0.11	-0.33	0.32	0.56	-0.15	0.05	0.35	0.10	0.24
Citizenship	0.20	0.20	0.07	-0.37	0.11	0.54	-0.22	0.42	0.18	0.31	0.23
Promoting diversity	0.27	0.10	-0.18	-0.31	0.08	0.49	-0.14	0.29	0.24	0.23	<u>0.45</u>
Critical thinking	0.19	0.16	0.24	-0.21	0.21	0.15	-0.72	0.07	0.15	0.26	0.17
Sourcing info	0.20	0.17	0.32	-0.15	0.17	0.12	-0.72	-0.03	0.27	0.36	0.15
Creativity	0.25	0.23	0.18	-0.34	0.19	0.17	-0.70	0.32	0.26	0.26	0.31
Embracing change	0.13	0.22	0.07	-0.30	<u>0.39</u>	0.23	-0.66	0.40	0.24	0.24	0.17
Problem-solving	0.10	0.27	0.25	-0.16	0.23	0.14	-0.56	0.06	0.29	0.29	0.11
Flexibility	0.30	-0.03	0.15	-0.24	0.13	0.12	-0.50	0.20	<u>0.49</u>	0.33	0.23

Systems	0.22	0.33	0.02	-0.24	<u>0.38</u>	0.15	-0.43	0.28	0.29	0.25	0.27
Design	0.04	0.37	0.01	-0.26	0.36	0.15	-0.39	-0.05	0.24	0.34	0.17
Entrepreneurship	0.32	0.25	0.09	-0.29	0.13	0.26	-0.26	0.61	0.24	0.09	0.31
Marketing	0.31	0.08	0.07	-0.27	0.10	0.21	-0.15	0.53	0.13	0.13	0.25
Keeping up to date	0.09	0.26	0.08	-0.37	0.09	0.38	-0.31	0.49	0.22	0.45	0.20
Cross-fn familiarity	0.40	0.00	0.01	-0.26	0.14	0.31	-0.24	0.13	0.60	0.19	0.31
Liability	0.23	0.14	0.20	-0.21	0.14	0.29	-0.11	-0.05	0.59	0.18	0.20
Life-cycle	0.21	0.12	0.03	-0.22	0.41	0.13	-0.20	0.14	0.47	0.22	0.32
Generalisation	0.09	0.37	0.04	-0.21	0.23	0.24	-0.38	0.39	0.42	0.16	0.09
Managing development	0.24	0.05	0.12	-0.41	0.08	0.27	-0.29	0.12	0.16	0.65	0.17
Self-management	0.18	0.12	0.18	-0.44	0.06	0.10	-0.26	-0.01	0.21	0.58	0.14
Info-management	0.20	0.24	0.35	-0.25	0.09	0.15	-0.26	0.03	0.24	0.54	0.17
Action orientation	0.38	-0.02	0.10	-0.40	0.16	0.18	-0.34	0.17	0.26	0.48	0.34
Managing comm.	0.15	0.03	0.36	-0.21	0.09	0.17	-0.29	0.18	0.33	0.48	0.20
Diversity skills	0.22	0.13	0.03	-0.24	0.08	0.23	-0.30	0.16	0.25	0.18	0.61
Interdisc. skills	0.33	-0.05	0.36	-0.23	0.14	0.20	-0.15	-0.01	0.28	0.10	0.45
Presenting	0.28	-0.05	0.41	-0.29	0.03	0.23	-0.37	0.42	0.25	0.30	0.43
Teamwork	0.37	-0.06	0.22	-0.18	0.32	0.08	-0.22	-0.11	0.33	0.34	0.43
Working internat.	0.08	0.18	-0.04	-0.21	0.20	0.12	-0.08	0.30	0.12	0.10	0.37

Notes:

- Shading indicates competencies reflecting factors.
- Underlining indicates violations of discriminant validity.
- Full names for the competencies are listed in Table 17.

In order to refine the factor structure, variables were removed iteratively. The eleven factors remained, although there were small changes to the variables reflecting some factors. Principal axis factoring and direct oblimin rotation were used throughout the analyses.

The factors were intended to be a tool to assist the measurement and interpretation of competencies. Therefore, variables were not removed simply based on whether they clearly reflected one factor considerably more than other factors. Instead, any competencies considered for removal from the factor model were required to satisfy the

following criteria, in addition to damaging discriminant validity as demonstrated by the structure matrix.

Criteria for Removal of a Competency

A competency was considered for removal from the model if there was a conceptual reason that the competency did not fit as neatly as other items reflecting its factor was also required and:

- it received relatively low ratings of importance in Surveys 1 and 2 and it was not an essential competency, such as a graduate attribute listed by EA, despite its low rating of importance
- or it was largely represented by remaining competencies reflecting the factor it reflected.

A refined factor structure was identified with eleven competency variables removed from the analysis. Variables were considered for removal if a variable from a different factor contributed more to the factor reflected by the variable in question. Variables were removed or re-introduced one at a time between iterations. A model exhibiting discriminant validity was identified with eleven variables removed from the analysis for the following reasons:

1. *Working internationally* was removed first because it had the lowest structure coefficient of all variables, and thereby caused discriminant validity to suffer. This competency had received the lowest mean rating of importance in both surveys.
2. *Practical* was removed because it had the next lowest structure coefficient and *embracing change, life-cycle, sustainability, and aesthetics*, from outside its factor, correlated more strongly with the factor. Despite its relatively high importance ratings, this variable could be considered to be an overarching term for the other

variables reflecting its factor, and therefore satisfied the criteria for removal from the model.

3. *Negotiation* was removed, although *design* had the lowest structure coefficient. *Design* was kept because no variable outside its factor was more highly correlated with its factor. *Negotiation* was removed because *safety* and *networking* from outside the Management/Leadership Factor correlated more highly with the factor than did *negotiation*. *Negotiation* was rated as important and therefore its removal was a borderline decision. It was not later re-introduced because *safety* and *networking* remained in the final factor structure, and continued to reflect variables other than the Management/Leadership Factor. *Negotiation* can be seen conceptually as a competency that reflects multiple factors.
4. *Generalisation* was removed because it had the next lowest structure coefficient and *meeting skills* and *focus*, from outside its factor, correlated more highly with the Engineering Business Factor than did *generalisation*. Although *focus* reflected the Engineering Business Factor in later structure models, *meeting skills* continued to reflect the Management/Leadership Factor, causing cross loading that prevented re-introduction of *generalisation*.
5. *Mentoring* was removed because it had the next lowest structure coefficient and *focus*, *networking* and *safety*, from outside its factor, were more highly correlated with the Management/Leadership Factor than was *mentoring*. *Focus*, *networking*, and *safety* remained in the final analysis, and therefore prevented inclusion of *mentoring*.
6. *Aesthetics* was removed. *Life-cycle* had the next lowest structure coefficient but its removal was delayed in an attempt to retain at least three variables reflecting the Engineering Business Factor. Justification to include the Engineering Business Factor is discussed later. *Promoting diversity* had the next lowest structure

coefficient but was retained because no variables from outside its factor correlated more highly with the factor. *Aesthetics* was removed because it did not fit conceptually with the other variables in the Applying Technical Theory factors, and because *integrated design*, from outside the factor, correlated more highly with the factor than did *aesthetics*. *Integrated design* remained in the final structure.

7. *Citizenship* was selected for removal from remaining variables that were causing cross loading, partly because it received the second lowest mean rating of importance in both surveys, but also because this change allowed *presenting* to remain in the Innovation Factor without *citizenship* correlating more highly with the factor despite being in the Contextual Responsibilities Factor.
8. *Life-cycle* was eventually removed because *flexibility* and *focus*, from outside the Engineering Business Factor, were more highly correlated with the factor.
9. *Promoting diversity* was removed because *ethics* from outside its factor was more highly correlated with the factor. In the subsequent factor analysis, *focus* now reflected the Engineering Business Factor, which improved the structure because this factor was again reflected by three variables, rather than only two.
10. *Workplace politics* was removed because *focus* was more highly correlated than *workplace politics* with the Management/Leadership Factor. *Workplace politics* received relatively low mean ratings of importance (3.3 from the established engineers and 3.2 from the senior engineers) on the scale (1 = *not needed*; 5 = *critical*). A ten-factor analysis was attempted to avoid removing *workplace politics*, however the result was conceptually unclear, with *liability* and *cross function familiarity* joining the competencies that reflected the Working in Diverse Teams Factor.
11. *Self-motivation* was removed because it was reflecting the Professionalism Factor and was correlated more weakly with the factor than *community*, which reflected a different factor. This was justified conceptually, because *self-motivation* can equally well be argued as reflecting the Professionalism or the Self-management Factor. *Self-motivation* did receive high ratings of importance. However, the decision to remove it satisfied the criteria for

removal of a competency from the model, because *self-motivation* could be considered to be included in *self-management*, which received even higher ratings than *self-motivation* in Survey 1.

Attempts were made to re-introduce *practical* and *workplace politics*. However, these changes created discriminant validity violations elsewhere in the structure.

The SPSSTM syntax for the factor analysis of the remaining 53 variables, using principal axis factoring and direct oblimin rotation is provided in Appendix XXIII.

Kaiser's measure of sampling adequacy was 0.89. Bartlett's test of sphericity was significant ($\chi^2(1378) = 0.007, p < 0.001$). Most off-diagonal elements of the anti-image had magnitudes less than 0.1. Eleven initial factors (as would have been explained by principal components analysis) explained 60% of the variance of the 53 remaining competency variables. The factors extracted using principal axis factoring explained 50% of the variance of the 53 competency variables.

With the 53 remaining variables, the scree plot now suggested seven factors. However, even with the reduced number of variables, the eleven-factor structure (Tables 23 and 24) was selected as conceptually superior to structures with other numbers of factors. The eleven factors can be considered to be generic engineering competency factors because they were revealed among the generic engineering competencies identified and confirmed in previous chapters of the thesis.

Comments in responses from senior engineers in Survey 2 stated that competencies, such as financial management and risk management, were not sufficiently emphasised in the list of competencies. If these had been additional stand-alone items, rather than included in other items such as management, then the Engineering Business Factor would probably have been reflected by more than three variables. The comments from the senior engineers instil confidence that the Engineering Business Factor is a true generic engineering competency factor.

The internal reliability of each factor is included in Table 24. Before calculating these, SPSSTM 17.0 2008 was used to check that each factor was unidimensional. The SPSSTM syntax and the scree plots for each factor, which reveal that each was unidimensional, are listed in Appendix XXIV.

Table 23. Pattern matrix from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), using principal axis factoring, direct oblimin rotation, 11 factors, and 53 selected competencies

<i>Competency</i>	<i>Factor</i>										
	1	2	3	4	5	6	7	8	9	10	11
Critical thinking	0.70	0.02	0.04	-0.03	0.05	0.03	0.06	0.08	-0.08	-0.01	-0.04
Sourcing info	0.67	0.05	-0.01	0.07	0.15	-0.01	0.07	0.16	0.04	0.09	-0.04
Creativity	0.61	0.10	-0.03	-0.12	-0.18	-0.01	0.06	-0.01	0.00	-0.05	-0.12
Embracing change	0.53	-0.01	0.27	-0.06	-0.29	0.04	-0.14	-0.07	0.03	0.04	0.03
Problem-solving	0.46	0.15	0.05	0.04	0.05	0.02	-0.03	0.14	0.08	0.06	-0.01
Flexibility	0.32	-0.11	0.07	0.03	-0.15	-0.10	0.01	0.02	0.32	0.17	-0.05
Design	0.28	0.28	0.15	-0.13	0.21	0.03	-0.04	-0.14	0.06	0.16	-0.05
Systems	0.27	0.22	0.22	-0.05	-0.16	-0.05	0.08	-0.07	0.07	0.05	-0.04
Theory	0.01	0.65	0.01	-0.03	-0.02	0.05	-0.08	0.09	0.07	0.05	-0.02
3D skills	0.05	0.61	0.11	-0.06	0.00	0.02	0.15	0.04	0.12	-0.07	0.08
Modelling	0.23	0.51	0.01	0.08	-0.07	0.06	-0.14	-0.02	-0.05	0.09	-0.01
Research	0.19	0.41	-0.01	0.06	-0.32	0.25	-0.18	0.01	-0.06	0.09	-0.04
Maintainability	0.13	-0.18	0.71	0.01	0.06	0.16	-0.05	0.00	0.07	-0.03	0.00
Manufacturability	-0.13	0.27	0.61	-0.07	-0.08	0.02	0.02	-0.01	-0.15	0.01	-0.13
Reliability	0.06	0.08	0.50	-0.01	0.05	0.14	-0.09	0.12	0.15	0.02	0.08
Integrated design	0.12	0.36	0.43	-0.07	-0.10	0.02	0.06	-0.05	-0.09	-0.01	-0.08
Honesty	-0.01	-0.01	0.01	-0.77	-0.11	-0.04	-0.06	0.00	0.02	-0.03	-0.09
Loyalty	-0.02	0.05	0.11	-0.75	-0.09	-0.13	-0.04	0.09	0.07	0.01	0.00
Commitment	0.09	-0.01	-0.02	-0.62	0.09	0.14	0.09	0.02	-0.10	0.11	-0.07
Ethics	0.01	0.03	-0.11	-0.56	0.12	0.38	-0.06	-0.03	0.07	0.01	-0.04
Demeanour	-0.09	0.01	0.00	-0.51	-0.14	-0.11	-0.03	0.03	0.06	0.24	-0.16
Concern for others	0.10	-0.07	0.12	-0.46	0.06	0.21	0.21	0.07	0.03	0.08	0.22
Entrepreneurship	0.00	0.21	0.04	-0.10	-0.59	0.01	0.12	0.03	0.07	-0.10	-0.10
Marketing	-0.02	0.03	0.04	-0.11	-0.50	0.02	0.16	0.06	-0.02	-0.01	0.03

Networking	0.02	-0.08	-0.10	0.00	-0.42	0.09	0.30	-0.05	0.07	0.13	-0.08
Presenting	0.18	-0.14	-0.09	-0.05	-0.39	0.10	0.01	0.24	-0.02	0.10	-0.25
Keeping up to date	0.08	0.14	-0.04	-0.12	-0.35	0.20	-0.12	-0.04	0.07	0.30	0.05
Sustainability	0.05	-0.04	0.19	0.01	0.09	0.71	0.05	0.10	0.06	-0.09	-0.11
Social context	-0.07	0.08	0.07	0.12	-0.09	0.70	0.07	0.02	0.02	0.08	-0.12
Community	0.02	0.10	0.04	-0.30	-0.11	0.58	0.01	0.00	0.08	0.07	0.12
Safety	-0.05	-0.13	0.21	-0.13	-0.02	0.39	0.20	0.01	0.28	-0.09	0.03
Supervising	-0.06	0.04	-0.01	0.01	-0.12	0.05	0.71	0.00	-0.06	0.08	-0.07
Coordinating	0.03	0.06	0.03	-0.01	0.06	0.02	0.65	0.17	0.06	-0.05	-0.11
Managing	0.02	-0.05	-0.08	0.03	-0.03	0.08	0.64	0.01	0.04	0.04	-0.09
Leading	0.12	-0.03	0.01	-0.11	-0.21	-0.05	0.57	0.03	0.20	-0.13	0.05
Risk-taking	-0.03	-0.07	0.17	0.03	-0.23	0.10	0.44	-0.14	0.14	0.17	0.08
Decision-making	0.10	0.02	0.01	-0.01	0.13	-0.01	0.44	0.03	0.11	0.26	-0.09
Meeting skills	0.25	-0.14	-0.11	-0.04	-0.04	0.05	0.38	0.09	0.26	-0.07	-0.07
Graphical comm.	0.01	0.15	0.17	0.03	0.04	0.02	0.12	0.57	-0.06	-0.06	0.00
English	0.16	-0.10	-0.11	-0.14	-0.08	0.01	-0.02	0.54	-0.04	0.03	0.01
Written comm.	-0.01	0.15	-0.10	0.00	-0.07	0.09	-0.10	0.46	0.15	0.22	-0.03
Verbal comm.	0.13	-0.14	0.06	-0.04	-0.03	0.03	0.09	0.45	0.07	0.10	-0.12
Liability	-0.11	0.17	-0.03	-0.01	0.12	0.08	-0.03	0.08	0.65	0.01	-0.08
Cross-fn familiarity	0.04	-0.01	0.02	-0.02	-0.08	0.03	0.07	-0.12	0.62	0.00	-0.09
Focus	0.10	-0.09	0.08	-0.16	-0.14	0.00	0.25	-0.06	0.35	0.04	0.06
Managing development	0.06	-0.03	0.01	-0.17	0.00	0.11	0.11	-0.03	-0.04	0.56	0.07
Info-management	-0.03	0.19	0.01	-0.03	0.06	-0.02	0.10	0.22	0.03	0.46	-0.08
Self-management	0.09	0.09	-0.10	-0.26	0.13	-0.02	0.07	0.02	0.05	0.44	0.05
Managing comm.	0.02	-0.09	0.06	0.04	-0.14	0.03	-0.10	0.21	0.12	0.43	-0.13
Action orientation	0.16	-0.09	0.09	-0.17	-0.05	-0.06	0.18	-0.04	0.09	0.31	-0.06
Interdisc. skills	-0.04	-0.09	0.03	-0.10	0.04	0.11	0.07	0.13	0.11	-0.10	-0.54
Diversity skills	0.16	0.08	-0.04	-0.10	-0.09	0.07	0.04	-0.15	0.06	-0.01	-0.41
Teamwork	0.05	-0.09	0.23	-0.01	0.20	-0.05	0.19	0.03	0.09	0.19	-0.35

Notes:

- Shading indicates competencies reflecting factors.
- Full names for the competencies are listed in Table 17.

Table 24. Generic engineering competency factors identified from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), analysed using principal axis factoring, direct oblimin rotation, 11 factors, and 53 selected competencies

<i>Factor number</i>	<i>Factor name</i>	<i>Competencies reflecting factor</i>	<i>α</i>
1	Creativity / Problem-Solving	Critical thinking, Sourcing info, Creativity, Embracing change, Problem-solving, Flexibility, Design, Systems	0.82
2	Applying Technical Theory	Theory, 3D skills, Modelling, Research	0.74
3	Practical Engineering	Maintainability, Manufacturability, Reliability, Integrated design	0.75
4	Professionalism	Honesty, Loyalty, Commitment, Ethics, Demeanour, Concern for others	0.84
5	Innovation	Entrepreneurship, Marketing, Networking, Presenting, Keeping up to date	0.73
6	Contextual Responsibilities	Sustainability, Social context, Community, Safety	0.81
7	Management/Leadership	Supervising, Coordinating, Managing, Leading, Risk-taking, Decision-making, Meeting skills	0.85
8	Communication	Graphical comm., English, Written comm., Verbal comm.	0.66
9	Engineering Business	Liability, Cross-fn familiarity, Focus	0.65
10	Self-management	Managing development, Info-management, Self-management, Managing comm., Action orientation	0.71
11	Working in Diverse Teams	Interdisc. Skills, Diversity skills, Teamwork	0.55

Note: Full names for the competencies are listed in Table 17.

There were no high correlations between the factors, the highest magnitude being 0.38 (Table 25). The structure matrix, which can be calculated from the pattern matrix and the factor correlation matrix, was no longer different from the pattern matrix in its allocation of competencies to reflect each factor, and each competency correlated most highly with the factor it reflects (Table 23, Table 26). Therefore, the eleven-factor

structure reflected by the 53 selected competencies represents distinctly defined weakly correlated factors.

Table 25. Factor correlation matrix for factor analysis of importance ratings made by established engineers in Survey 1 ($N = 300$), using principal axis factoring, direct oblimin rotation, 11 factors, and 53 selected competencies

<i>Factor</i>	1	2	3	4	5	6	7	8	9	10	11
1	1.00	0.22	0.26	-0.25	-0.21	0.17	0.17	0.21	0.27	0.35	-0.23
2		1.00	0.27	-0.10	-0.11	0.17	-0.14	0.07	0.01	0.15	-0.06
3			1.00	-0.14	-0.05	0.27	0.17	0.04	0.19	0.06	-0.10
4				1.00	0.21	-0.27	-0.24	-0.10	-0.28	-0.35	0.16
5					1.00	-0.15	-0.19	0.00	-0.14	-0.13	0.14
6						1.00	0.16	0.15	0.30	0.16	-0.14
7							1.00	0.11	0.38	0.16	-0.25
8								1.00	0.15	0.22	-0.22
9									1.00	0.27	-0.27
10										1.00	-0.21
11											1.00

Note: Shading indicates values with the highest magnitudes.

Table 26. Structure matrix from factor analysis of competency importance ratings made by established engineers in Survey 1 ($N = 300$), using principal axis factoring, direct oblimin rotation, 11 factors, and 53 competencies

	<i>Factor</i>										
<i>Competency</i>	1	2	3	4	5	6	7	8	9	10	11
Critical thinking	0.73	0.18	0.23	-0.22	-0.11	0.17	0.17	0.23	0.17	0.26	-0.22
Sourcing info	0.72	0.19	0.19	-0.15	-0.02	0.14	0.18	0.34	0.26	0.35	-0.25
Creativity	0.71	0.25	0.19	-0.32	-0.36	0.18	0.22	0.16	0.25	0.27	-0.30
Embracing change	0.66	0.24	0.41	-0.29	-0.41	0.25	0.08	0.06	0.23	0.27	-0.14
Problem-solving	0.56	0.29	0.23	-0.15	-0.08	0.18	0.08	0.27	0.23	0.27	-0.17
Flexibility	0.48	0.00	0.17	-0.22	-0.26	0.10	0.26	0.16	0.46	0.37	-0.25
Systems	0.45	0.34	0.38	-0.24	-0.29	0.16	0.20	0.05	0.24	0.24	-0.19
Design	0.42	0.40	0.33	-0.27	0.05	0.19	0.04	0.01	0.20	0.32	-0.16
Theory	0.22	0.70	0.21	-0.15	-0.11	0.21	-0.10	0.16	0.10	0.20	-0.10
3D skills	0.25	0.62	0.33	-0.19	-0.12	0.22	0.14	0.10	0.20	0.12	-0.06
Modelling	0.34	0.60	0.18	-0.05	-0.15	0.15	-0.17	0.06	-0.01	0.20	-0.07
Research	0.36	0.56	0.19	-0.14	-0.40	0.35	-0.12	0.10	0.06	0.24	-0.13
Maintainability	0.29	0.06	0.74	-0.14	-0.01	0.34	0.16	0.07	0.25	0.06	-0.11
Manufacturability	0.12	0.42	0.66	-0.16	-0.13	0.22	0.08	0.03	0.02	0.07	-0.17
Reliability	0.26	0.27	0.59	-0.16	-0.01	0.33	0.07	0.18	0.27	0.14	-0.06

Integrated design	0.34	0.51	0.57	-0.21	-0.20	0.23	0.12	0.03	0.09	0.13	-0.17
Honesty	0.21	0.08	0.11	-0.78	-0.26	0.19	0.17	0.09	0.23	0.26	-0.21
Loyalty	0.23	0.15	0.20	-0.77	-0.24	0.15	0.19	0.16	0.27	0.30	-0.15
Commitment	0.29	0.09	0.14	-0.71	-0.11	0.33	0.26	0.16	0.22	0.38	-0.22
Ethics	0.19	0.12	0.08	-0.64	-0.07	0.50	0.13	0.10	0.29	0.27	-0.16
Demeanour	0.19	0.09	0.07	-0.61	-0.26	0.11	0.19	0.14	0.27	0.44	-0.29
Concern for others	0.29	0.04	0.27	-0.60	-0.11	0.40	0.36	0.17	0.31	0.31	0.00
Entrepreneurship	0.24	0.27	0.18	-0.28	-0.67	0.21	0.27	0.08	0.24	0.12	-0.25
Marketing	0.16	0.08	0.11	-0.26	-0.55	0.17	0.28	0.08	0.16	0.13	-0.11
Networking	0.21	-0.06	0.01	-0.25	-0.52	0.21	0.45	0.05	0.30	0.26	-0.25
Presenting	0.38	-0.01	0.01	-0.28	-0.48	0.24	0.24	0.36	0.25	0.33	-0.42
Keeping up to date	0.32	0.28	0.10	-0.36	-0.45	0.35	0.05	0.08	0.24	0.44	-0.11
Sustainability	0.23	0.13	0.41	-0.22	-0.05	0.79	0.23	0.24	0.34	0.10	-0.26
Social context	0.15	0.21	0.28	-0.16	-0.21	0.75	0.21	0.16	0.28	0.19	-0.25
Community	0.27	0.26	0.28	-0.53	-0.28	0.72	0.20	0.13	0.35	0.30	-0.08
Safety	0.14	-0.04	0.36	-0.33	-0.15	0.55	0.42	0.11	0.50	0.09	-0.15
Supervising	0.13	-0.04	0.12	-0.21	-0.26	0.18	0.73	0.10	0.26	0.20	-0.26
Coordinating	0.21	-0.01	0.20	-0.21	-0.10	0.20	0.71	0.28	0.36	0.15	-0.32
Leading	0.28	-0.07	0.17	-0.31	-0.36	0.16	0.70	0.11	0.45	0.11	-0.19
Managing	0.15	-0.13	0.07	-0.19	-0.18	0.19	0.70	0.13	0.33	0.18	-0.28
Risk-taking	0.18	-0.04	0.27	-0.23	-0.35	0.26	0.57	-0.04	0.38	0.26	-0.12
Meeting skills	0.36	-0.15	0.06	-0.25	-0.20	0.20	0.56	0.23	0.50	0.18	-0.29
Decision-making	0.30	0.02	0.16	-0.25	-0.04	0.16	0.54	0.19	0.38	0.41	-0.29
Graphical comm.	0.17	0.20	0.23	-0.06	0.02	0.15	0.15	0.58	0.08	0.09	-0.15
English	0.27	-0.03	-0.05	-0.23	-0.12	0.11	0.10	0.58	0.11	0.22	-0.16
Verbal comm.	0.32	-0.05	0.14	-0.22	-0.12	0.20	0.28	0.54	0.30	0.31	-0.32
Written comm.	0.23	0.22	0.02	-0.19	-0.13	0.24	0.04	0.54	0.27	0.39	-0.22
Cross-fn familiarity	0.24	0.01	0.18	-0.24	-0.21	0.25	0.35	0.02	0.69	0.20	-0.27
Liability	0.11	0.16	0.14	-0.19	0.02	0.28	0.20	0.19	0.65	0.20	-0.25
Focus	0.30	-0.04	0.22	-0.37	-0.28	0.22	0.47	0.05	0.54	0.25	-0.16
Managing development	0.30	0.08	0.10	-0.41	-0.15	0.24	0.24	0.12	0.23	0.64	-0.11
Self-management	0.29	0.15	0.02	-0.42	-0.02	0.14	0.18	0.16	0.25	0.57	-0.12
Info-management	0.25	0.25	0.11	-0.25	-0.05	0.15	0.19	0.36	0.24	0.56	-0.26
Managing comm.	0.28	0.04	0.10	-0.21	-0.21	0.18	0.12	0.34	0.29	0.52	-0.30
Action orientation	0.37	0.01	0.19	-0.39	-0.20	0.14	0.37	0.11	0.34	0.47	-0.25
Interdisc. skills	0.15	-0.05	0.13	-0.22	-0.08	0.24	0.30	0.27	0.33	0.11	-0.61
Diversity skills	0.30	0.15	0.12	-0.25	-0.23	0.20	0.21	0.01	0.25	0.19	-0.47
Teamwork	0.25	-0.02	0.29	-0.19	0.07	0.12	0.36	0.19	0.33	0.32	-0.47

Notes:

- Shading indicates competencies reflecting factors.
- Full names for the competencies are listed in Table 17.

Importance ratings for each factor were calculated as the mean of the importance ratings for the competencies reflecting the factor (Figure 9). The SPSSTM syntax is in Appendix XXIV.

Figure 9. Generic engineering competency factor mean importance ratings (+SE) (based on 53 competencies that have not been normalised) (N = 300)

The generic engineering competency factors did not have normal distributions (Table 27). The frequency distributions are in Appendix XXIV. The Communication Factor and Working in Diverse Teams Factor were especially skewed towards the top of the scale (Figure 57, Figure 60).

Table 27. Distribution statistics for generic engineering competency factor importance ratings across Survey 1 of established engineers (based on 53 competencies that have not been normalised) (N = 300)

<i>Factor</i>	<i>Mean</i>	<i>SE</i>	<i>SD</i>	<i>Skew</i>	<i>SE of skew</i>	<i>Kurtosis</i>	<i>SE of kurtosis</i>
Communication	4.4	0.029	0.50	-0.98	0.14	1.64	0.28
Working in Diverse Teams	4.2	0.037	0.65	-1.04	0.14	1.46	0.28
Professionalism	4.2	0.035	0.60	-0.72	0.14	0.61	0.28
Self-management	4.2	0.030	0.53	-0.50	0.14	0.17	0.28
Creativity / Problem-Solving	3.9	0.034	0.59	-0.31	0.14	-0.44	0.28
Management/Leadership	3.9	0.043	0.75	-0.87	0.14	0.78	0.28
Engineering Business	3.6	0.045	0.78	-0.61	0.14	0.52	0.28
Innovation	3.3	0.044	0.77	-0.19	0.14	-0.06	0.28
Practical Engineering	3.2	0.052	0.90	-0.44	0.14	0.01	0.28
Contextual Responsibilities	3.1	0.057	0.98	-0.29	0.14	-0.58	0.28
Applying Technical Theory	2.9	0.054	0.94	0.10	0.14	-0.80	0.28

7.4. Discussion

The generic engineering competency factor importance ratings confirm, as discussed in Chapter 6, that non-technical competencies were rated as most important on average. Although not the sole purpose of the factor analysis, the simplification that the eleven-factor competency model provides for comparison of factor ratings is apparent in Figure 9.

The factors represent groups of competencies important in similar jobs. These factors are suitable for profiling of graduates, to evaluate the success of a program in developing competencies needed for engineering work. The grouping process contrasts with the conceptual grouping of competencies in accreditation criteria, in which outcomes are grouped with other outcomes that are similar in nature. Despite the different systems of grouping, the factor structure identified in this study more closely resembles the grouping of outcomes as listed by ABET and EA than by the ENAEE.

However, only the ENAEE outcomes include business skills, which appear as the Engineering Business Factor in the eleven-factor generic engineering competency model.

The Innovation Factor is additional to the outcomes stipulated for accreditation by ABET, EA, and the ENAEE. Ferguson (2006a) and Radcliffe (2005) had recognised that outcomes stipulated by program accreditation criteria were not sufficient for the development of innovation, although Radcliffe conceptualised innovation as an overarching meta cognition, rather than an identifiable competency factor. The diversity of competency items reflecting the Innovation Factor (including entrepreneurship, marketing and networking) highlights this study's empirical grouping of competencies by jobs in which they are needed rather than whether the competencies are similar in nature. The Factor was later renamed Entrepreneurship (Chapter 9).

7.5. Conclusions

Chapter 6 analysed the ratings for each competency individually. In Chapter 7 a factor structure was empirically identified within the competencies that are important to engineers graduating in Australia. The factor structure consists of eleven weakly correlated factors reflected by 53 competencies and satisfying discriminant validity. Within this study the factors will simplify comparison of competency ratings across sample groups. However, the method was selected to identify factors that will be useful for future applications of the results.

For engineering educators, the eleven generic engineering competency factors provide a simple model of the competencies important to engineers graduating in Australia and could be used to assist evaluation of engineering programs in Australia. Similar studies using different samples of engineers, and different methods, are required for validation.

The competency factors provide insight into possible refinements of accreditation criteria for Australian engineering education programs.

CHAPTER 8. Comparison of Importance of Competencies across Jobs

8.1. *Introduction*

This chapter addresses the second sub-question of this thesis:

Are different generic engineering competencies important for jobs with different tasks and work contexts?

Chapter 6 confirmed 64 competencies as important for an established engineer to perform his or her job well. Chapter 7 identified eleven factors among these competencies and defined each factor's importance rating as the mean ratings of importance for the competencies that reflect the factor. We now compare factor importance ratings across sample groups in Survey 1.

8.1.1. Theoretical Rationale

The theoretical framework, adapted from the DeSeCo Project (OECD 2003), and introduced in Chapter 1, views competencies as existing in constellations with relative importance influenced by a person's demands and context. In the CEG Project, the DeSeCo framework was adapted to imply that competencies that are important for an engineer's work would be influenced by the tasks and work context entailed in the engineer's job. Therefore, the theoretical framework of the CEG Project implies that the competency factor importance ratings can be expected to vary across engineering jobs. In this chapter, the extent of such variation in competency ratings is studied by comparing competency factor importance ratings across sample groups within Survey 1.

8.1.2. Significance

It is well recognised that society needs a diverse range of engineers (Johnson 1996b, Ihlen 2005, Spinks *et al.* 2006). Spinks *et al.* named three roles of engineers: “specialists”, “integrators”, and “change agents” (p.60). If there are clusters of jobs that demand significantly different competencies, then awareness of these will assist improvements to engineering education programs.

A potential application of the eleven competency factors identified in Chapter 7 is in the evaluation of Australian engineering education programs. It is envisaged that graduates from engineering programs could be rated on the eleven generic engineering competency factors by their workplace supervisors, to help evaluate engineering programs. If the importance of any generic engineering competency factor differs across engineering jobs, then it will be necessary to be aware of this because it will influence the validity of the ratings. It could be expected that generic engineering competency factors would be rated most accurately in engineering jobs for which the competency factors are most important.

8.2. Method

Generic engineering competency factor importance ratings, defined in Chapter 7, were compared across Survey 1 sample groups. This was achieved using multivariate analysis of variance (MANOVA) to compare factor importance ratings across personal demographics, key responsibilities, tasks, and work contexts. The analysis was performed using SPSSTM 17.0 2008. Syntax is presented in Appendix XXV.

Before MANOVAs were performed, descriptive charts were used to examine the data. Q-Q plots looked reasonably normal, except for a relatively small number of variables. Outliers were present but were not removed as the scale was short. Box’s M Test was used to confirm homogeneity of the variance-covariance matrices ($p > 0.001$), and

Bartlett's Test was used to confirm that there was sufficient correlation between competency factor importance ratings ($p < 0.001$). Wilk's λ was used as the measure for significance of the multivariate variance. If Box's M Test was significant, and cells with smaller sample sizes corresponded to larger variances and covariances in the competency factor importance ratings, then Pillai's Trace was used as the multivariate test, as recommended by Tabachnick and Fidell (2001).

Univariate tests were performed when the multivariate test was significant. In this case, Levene's Test of Equality of Error Variance was used to test suitability of the data for analysis. When variables had more than two values, Tukey's *Post Hoc* Test was used. Otherwise univariate tests were used. This defeated the advantage of multivariate analysis, that the total error across all factor importance ratings was constrained to the set value of 0.05. For this reason, univariate tests are reported for both $p < 0.05$ and $p < 0.01$. We saw in Chapter 7 that the generic engineering competency factors are correlated. Therefore, it was likely that when one factor importance rating varied significantly across values of a variable, others would also, even without any additional effect.

8.2.1. Confounders

Because the method used to recruit survey participants was neither random nor purposive, there was over-representation of sample groups that could have confounded results. Demographic data were described in Chapter 6. The following characteristics of participants' personal backgrounds were tested for significant variance in factor importance ratings across sample groups, and when variance was significant, for interaction with relationships between job-related variables and the competency importance factors:

- country where participant was awarded undergraduate engineering qualification
- country where participant completed secondary education

- university that awarded participant's undergraduate engineering qualification
- participant's highest level of technical qualification
- participant's non-technical qualification
- gender
- age
- location where participant worked (WA versus other states of Australia)

Whether the participant worked in or outside Australia was treated as a characteristic of the job rather than a potentially confounding variable.

8.2.2. Job Related Variables

8.2.2.1. Work Context

The following characteristics of participants' work contexts were tested for relationships with the generic engineering competency factor importance ratings:

- engineering discipline in which participant was qualified (3 categories)
- location where participant worked (Australia or outside Australia)
- sector in which participant was employed (4 categories)
- size of organization in which participant was employed (3 categories)
- years that organization had provided current products or services (2 categories)
- extent to which role was technical (3 categories)
- work time spent in regional, remote or off-shore locations (2 categories)

Although the participants' engineering disciplines were characteristics of the participants, rather than their jobs, these were likely to also transfer to disciplines of the jobs.

8.2.2.2. Key Responsibilities and Tasks

Each of the eight key responsibilities, listed in the questionnaire, was coded as a binary variable. Each was a participant's key responsibility, or it was not. MANOVAs were

used to analyse whether there was significant variance between the generic engineering competency factor importance ratings for participants with and without each key responsibility.

Each of the twelve task categories (Section IV of Appendix X) had been coded into three levels (0 = *participant performed no task in the category*; 1 = *participant performed at least one but fewer than half of the tasks in the category*; 2 = *participant performed at least half of the tasks in the category*). These levels were used in the descriptive analysis which revealed similarity between the tasks performed by participants and those demonstrated by applicants for chartered status in Western Australia (Chapter 6). For the purpose of analysis in this chapter, levels 1 and 2 were combined. MANOVAs discovered whether for each category of tasks there was significant variance in the generic engineering competency factor importance ratings between responses from participants performing fewer than half of the tasks in a category and those performing at least half of the tasks in the same category.

8.3. Results

8.3.1. Sample Characteristics Not Found to be Confounding

Most personal demographic characteristics were not found to be related to significant variance in competency factor importance ratings and therefore were not considered to be confounding variables.

The multivariate test did not indicate significant variance ($p < 0.05$) between the generic engineering competency factor importance ratings made by engineers in sample groups determined by: the country in which undergraduate engineering qualifications were completed, whether participants had technical qualifications, gender, age, or state or territory of Australia in which participants worked (Table 28).

Table 28. Multivariate test results for personal demographic variables that were not found to confound the competency factor importance ratings for Survey 1 of 300 established engineers

<i>Demographic variables and values</i>	<i>n</i>	<i>Wilk's λ</i>	<i>df</i>	<i>Error df</i>	<i>F</i>	<i>p</i>	<i>partial η^2</i>
<i>Country in which undergraduate engineering education was completed</i>							
Australia	271	0.94	11	288	1.60	0.10	0.06
Other	29						
<i>Non-technical qualifications</i>							
None	270	0.96	11	287	1.18	0.30	0.04
Some	29						
<i>Gender</i>							
Male	245	0.96	11	288	1.22	0.28	0.04
Female	55						
<i>Age</i>							
25-29 years	43	0.86	33	843	1.35	0.09	0.05
30-34 years	114						
35-39 years	83						
40- years	60						
<i>State or Territory (among those working in Australia)</i>							
WA	226	0.02	11	252	0.98	0.46	0.04
Other	38						

8.3.2. Potentially Confounding Variables

8.3.2.1. Country Where Participant Completed

Secondary Education

Survey 1 participants who had completed their secondary education outside Australia rated competencies in the Professionalism and Self-Management Factors as more important to performing their work well than did other participants.

The multivariate test indicated significant variance between the generic engineering competency factor importance ratings made by engineers who completed their secondary education in Australia ($n = 252$) and those who completed secondary education outside Australia ($n = 48$) (Wilk's $\lambda = 0.93$, $F(11, 288) = 2.00$, $p = 0.03$, partial $\eta^2 = 0.07$). Univariate ANOVAs indicated that four factors were rated significantly differently across the two groups. Factor importance ratings for Applying Technical Theory, Professionalism, Innovation, and Self-Management were higher for

participants who had completed their secondary education outside Australia than participants who had completed their secondary education in Australia (Figure 10). Therefore, this personal characteristic was tested for interactions with the job-related variables and the generic engineering competency factor importance ratings to check whether it could be influencing results.

Figure 10. Generic engineering competency factor importance rating means (+ SE) by country in which participant completed secondary education, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.2.2. Over-Representation of UWA Graduates

UWA graduates in Survey 1 rated competencies in the Contextual Responsibilities Factor as less important to their work than did other participants.

The multivariate test indicated significant variance between the generic engineering competency factor importance ratings made by engineers who were awarded their undergraduate engineering qualifications by UWA ($n = 217$) and other participants ($n = 83$) (Wilk's $\lambda = 0.91$, $F(11,288) = 2.54$, $p < 0.01$, partial $\eta^2 = 0.09$). However, only the Contextual Responsibilities Factor was rated significantly differently by the two sample groups ($F(1,298) = 19.7$, $p < 0.01$, partial $\eta^2 = 0.06$). Competency ratings made by participants with bachelors of engineering from UWA indicated that the Factor was less important ($M = 2.9$, $SE = 0.06$) than was indicated by the importance based on ratings made by other participants ($M = 3.5$, $SE = 0.10$).

8.3.2.3. Level of Technical Qualification

In Survey 1, engineers with postgraduate technical qualifications rated competencies in the Applying Technical Theory Factor as more important to doing their work well than did other engineers.

The multivariate test indicated significant difference between the generic engineering competency factor importance ratings made by engineers with *postgraduate* technical qualifications ($n = 45$), honours as their highest technical qualification ($n = 151$) and other participants ($n = 103$) (Wilk's $\lambda = 0.87$, $F(22,572) = 1.93$, $p < 0.01$, partial $\eta^2 = 0.07$). The only competency factor rated significantly differently on average was the Applying Technical Theory Factor ($F(2,296) = 11.0$, $p < 0.01$, partial $\eta^2 = 0.04$). For participants with postgraduate technical qualifications the factor importance rating for Applying Technical Theory ($M = 3.2$, $SE = 0.14$) was significantly higher than for honours graduates ($M = 2.9$, $SE = 0.08$) or pass graduates ($M = 2.8$, $SE = 0.09$). This was considered most likely to be a result of the nature of the work

performed by engineers with various technical qualifications and therefore not likely to confound results in which the sample is grouped according to features of the work performed.

8.3.3. Work Context

MANOVAs were used to assess the variance between sample groups with different work contexts. Variables identifying dimensions of work context were considered one at a time. MANOVAs were also used to assess interactions with these variables and the two potentially confounding factors, whether participants completed their secondary education in Australia, and whether they had bachelors of engineering from UWA, on the competency factor importance ratings. One interaction was found, between the participant's discipline and whether the participant had completed secondary education in Australia.

8.3.3.1. Engineering Discipline

Civil engineers in Survey 1 rated Contextual Responsibility competencies higher than other engineers. However, the difference in competency ratings across disciplines might not have been as significant if more of the engineers had completed secondary education outside Australia.

The multivariate test indicated significant variance between the generic engineering competency factor ratings and the engineering disciplines of the participants in Survey 1 (Wilk's $\lambda = 0.74$, $F(22,572) = 4.25$, $p < 0.01$, partial $\eta^2 = 0.14$). Tukey's *Post Hoc* Tests indicated significant differences between the mean importance ratings for the Contextual Responsibilities Factor across the civil discipline area and the mechanical discipline area, and across the civil discipline area and the electrical discipline area. For the Communications Factor the difference was significant only between the civil discipline area and the electrical discipline area (Figure 11). As noted by a member of the Industry Advisory Committee, these significant differences could be partly

explained by extents to which jobs are isolated from, or closely associated with the community. Civil engineers often work in environments within the community.

Figure 11. Generic engineering competency factor importance rating means (+SE) by participant's discipline, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

Notes:

- Mean Contextual Responsibilities Factor importance rating was significantly different between participants with qualifications in the: electrical engineering and related fields, and civil engineering and related fields ($p < 0.01$); and between the civil engineering and related fields, and the mechanical engineering and related fields ($p < 0.05$).

- Mean Applying Technical Theory Factor importance rating was significantly different between participants with qualifications in, electrical engineering and related fields, and civil engineering and related fields ($p < 0.05$).

Multivariate interaction between the participating engineer's discipline and country of secondary education, on the generic engineering competency factor importance rating was significant (Pillai's Trace = 0.13, $F(22,568) = 1.74$, $p = 0.02$, partial $\eta^2 = 0.06$). The univariate tests indicated that the Contextual Responsibilities Factor was the only one with a significant interaction between discipline and country of secondary education ($F(2,293) = 3.54$, $p = 0.03$, partial $\eta^2 = 0.02$) (Figure 12). Therefore, caution is required if making any conclusions about differences across disciplines such as might be tempting based on the results in Figure 11 alone.

Figure 12. Contextual Responsibilities Factor importance rating mean (+SE) by participant's discipline and whether the participant completed secondary education in Australia, calculated from competency importance ratings made by engineers in Survey 1 ($N = 300$)

Note: The Contextual Responsibilities Factor importance rating was the only one for which the participant's discipline and country of secondary education interacted significantly ($p < 0.05$).

It is possible that the interaction between discipline and secondary education, on Contextual Responsibilities, could be partly explained by a relationship between the participants' backgrounds and jobs. As described later in section 8.3.3.5, government employees rated the importance of the Contextual Responsibility Factor significantly higher than did other survey participants (Figure 15).

The theory, about the interaction between disciplines and secondary education being partly due to the engineers' jobs, is supported. Among the engineers qualified in mechanical disciplines and electrical disciplines, higher percentages of the overseas secondary school graduates (15% and 22% respectively) than of Australian secondary school graduates (8% and 15% respectively) worked in government organizations or instrumentalities. However, in the civil disciplines, 25% of the overseas secondary graduates and 28% of the Australian secondary graduates worked in government positions. Coupled with the higher importance of Contextual Responsibilities to government employees noted above, these data are consistent with the smaller variation in the Contextual Responsibility Factor importance ratings across disciplines among the overseas secondary graduates (Figure 12). Hence, the interaction between discipline and location of secondary education is partly related to the participants' jobs.

8.3.3.2. Country Where Participant Was Working

In Survey 1, participants who were working outside Australia rated competencies in the Innovation Factor and the Working in Diverse Teams Factor as more important than did other participants.

Responses from participants who were working outside Australia reflected significantly different factor importance ratings from those working in Australia (Wilk's $\lambda = 0.92$, $F(11,288) = 2.38$, $p < 0.01$, partial $\eta^2 = 0.08$). The Innovation Factor and the Working

in Diverse Teams Factor importance ratings were higher for participants who were working outside Australia (Figure 13).

Figure 13. Generic engineering competency factor importance rating means (+SE) by whether participant was working in Australia, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.3.3. Work Time Spent in Rural, Remote or Offshore Locations

Survey 1 participants who were spending more than one third of their work time in rural, remote or offshore locations rated Applying Technical Theory competencies as less important, and Management/Leadership competencies as more important than did other participants.

Responses from participants who spent more work time in rural, remote or offshore locations than other participants indicated significantly lower factor importance ratings for Applying Technical Theory and Communication and significantly higher factor importance ratings for Management/Leadership and Working in Diverse Teams (Figure 14). The multivariate test was significant (Wilk's $\lambda = 0.92$, $F(11,288) = 3.76$, $p < 0.01$, partial $\eta^2 = 0.13$).

□ Responses from Engineers Spending 34%-100% of Their Work Time in Rural, Remote or Offshore Locations (n = 50)

■ Responses from Engineers Spending 0-33% of Their Work Time in Rural, Remote or Offshore Locations (n = 250)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 14. Generic engineering competency factor importance rating means (+SE) by percent of work time spent in rural, remote or offshore locations, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.3.4. Years Participant's Main Organization Had Provided its Current Main Service or Product

Survey 1 participants working in organizations that had provided their main product or service for no more than three years, rated Innovation and Communication competencies as more important to doing their work well than did other participants.

Only 16 participants in Survey 1 worked in organizations which had been providing their current main service or products for no more than three years. For these participants, the factor importance ratings for the Innovation Factor ($M = 3.9$, $SE = 0.19$) and the Communication Factor ($M = 4.7$, $SE = 0.12$) were significantly higher than for other participants (Innovation: $M = 3.3$, $SE = 0.04$, $F(1,297) = 11.4$, $p < 0.01$, partial $\eta^2 = 0.04$; Communication: $M = 4.4$, $SE = 0.03$, $F(1,297) = 5.93$, $p = 0.02$, partial $\eta^2 = 0.02$). The multivariate test was significant (Wilk's $\lambda = 0.87$, $F(11,287) = 3.97$, $p < 0.01$, partial $\eta^2 = 0.13$). Of the 16 participants, only two did not complete their undergraduate engineering degrees at UWA. Only one of the 16 was working outside Australia. The result is not surprising and it supports the internal validity of the factor importance ratings.

8.3.3.5. Sector

Applying Technical Theory competencies were rated significantly higher by Survey 1 participants working in universities or tertiary institutions than by any other participants.

Factor importance ratings for Contextual Responsibilities, Management/Leadership and Engineering Business were highest for government employees.

Whether the participant was an employee in the private sector ($n = 208$), government ($n = 51$), or in university/tertiary education ($n = 13$), or a proprietor or director in the private sector ($n = 27$) was related to variation in the generic engineering competency factor importance ratings (Wilk's $\lambda = 0.667$, $F(33,840) = 3.76$, $p < 0.01$, partial $\eta^2 = 0.126$). The univariate tests were significant for the Applying Technical

Theory ($F(3,295) = 9.58, p < 0.01$, partial $\eta^2 = 0.09$), Innovation ($F(3,295) = 3.94, p < 0.01$, partial $\eta^2 = 0.04$), Contextual Responsibilities ($F(3,295) = 5.31, p < 0.01$, partial $\eta^2 = 0.05$), Management/Leadership ($F(3,295) = 4.11, p < 0.01$, partial $\eta^2 = 0.04$) and Engineering Business Factors ($F(3,295) = 3.29, p < 0.02$, partial $\eta^2 = 0.03$).

Tukey's *Post Hoc* Tests indicated that the Applying Technical Theory Factor importance rating was significantly higher for participants in the university/tertiary education sector ($M = 4.1, SE = 0.25$) ($p < 0.02$). This was consistent with the result for participants with postgraduate technical qualifications.

The Innovation Factor was more important to participants who were proprietors or directors in private organizations than for employees in the private sector ($p < 0.03$).

Contextual Responsibilities competencies were rated as more important to their work by government employees than by employees or proprietor/directors in the private sector ($p < 0.01$). The Management/Leadership Factor competencies were rated as more important by government employees than by private proprietors/directors ($p < 0.01$). The Engineering Business Factor competencies were rated as more important by government employees than by private proprietors/directors ($p < 0.02$). The difference for the Management/Leadership and Engineering Business Factor importance rating draws attention to whether the size of the organization was important.

* Univariate significance across sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 15. Generic engineering competency factor importance rating means (+SE) by sector, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.3.6. Organization Size

In Survey 1, competencies in the Applying Technical Theory Factor received the highest importance ratings from participants in the smallest organizations and competencies in the Contextual Responsibilities, Management/Leadership, Engineering Business, and Working in Diverse Teams Factors received the highest importance ratings from participants in large organizations.

The multivariate test indicated a significant relationship between the number of employees in the organization in which the participant worked and the generic engineering competency factor importance ratings (Wilk's $\lambda = 0.76$, $F(22,574) = 3.92$, $p < 0.01$, partial $\eta^2 = 0.13$). Univariate tests were significant for the following factors: Applying Technical Theory, Contextual Responsibilities, Management/Leadership, Engineering Business, and Working in Diverse Teams. Tukey's *Post Hoc* Tests indicated that: Applying Technical Theory was more important on average to the work of participants in organizations with 0 to 50 employees than 51 to 500 employees ($p < 0.01$); the Contextual Responsibility Factor was more important on average for the work of participants in organizations of over 500 employees than in smaller organizations ($p < 0.01$); and the Management/Leadership ($p < 0.01$), Engineering Business ($p < 0.01$), and Working in Diverse Teams Factors ($p < 0.03$) were more important to the work of participants in organizations of over 500 employees than organizations of 0 to 50 employees (Figure 16). Therefore, competency factors that had higher factor importance ratings for participants from government organizations (Contextual Responsibilities, Management/Leadership, and Engineering Business), also had higher importance ratings for participants from organizations of over 500 employees.

Figure 16. Generic engineering competency factor importance rating means (+SE) by organization size, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

Although MANOVAs did not reveal interactions with the variables that could have confounded the results, a potential limitation arose from the imbalance in the representation of UWA graduates in organizations of different sizes within the sample.

All 51 participants from organizations with 0 to 50 employees, and 43 of the 46 participants from organizations with 50 to 500 employees, were UWA graduates. In contrast, only 123 of the 203 participants from organizations with over 500 employees had been awarded their undergraduate engineering degrees by UWA. As already noted, responses from UWA graduates reflected a lower importance rating for the Contextual Responsibilities Factor than did responses from other graduates, consistent with UWA graduates' relative over-representation in the smallest organizations.

8.3.3.7. Extent to Which Participant's Job was Technical

In Survey 1, the Communication Factor importance rating was higher on average for participants who rated their jobs as *mostly technical*, than for participants who rated their jobs as *not technical or hardly at all*.

Participants who rated their jobs as *not technical or hardly at all* rated Engineering Business competencies and Management/Leadership competencies as more important on average than they were rated by participants who rated their jobs as *mostly technical*.

Participants who rated their jobs as *mostly technical* rated Applying Technical Theory competencies, Practical Engineering competencies, and Creativity / Problem-Solving competencies as more important on average than did participants who rated their jobs as *not technical or hardly at all*.

Survey 1 participants rated their jobs as one of the following: *mostly technical*, *partly technical*, or *not technical or hardly at all*. The multivariate test indicated significant variance in the generic engineering competency factor importance ratings among the technical levels (Wilk's $\lambda = 0.62$, $F(22,574) = 7.06$, $p < 0.01$, partial $\eta^2 = 0.21$).

Univariate tests were significant for six of the eleven competency factor importance ratings (Figure 17). All varied as expected except one, the Communication Factor importance rating. This was higher for participants who rated their jobs as *mostly technical* ($M = 4.5$, $SE = 0.04$) than for participants who rated their jobs as *not technical or hardly at all* ($M = 4.2$, $SE = 0.09$) ($p < 0.02$). The factor importance ratings for

Working in Diverse Teams, Self-Management, Contextual Responsibilities, Innovation, and Professionalism did not vary significantly across the three sample groups.

As expected, Creativity / Problem-Solving, Applying Technical Theory and Practical Engineering factor importance ratings were higher for engineers performing jobs rated as *mostly technical*, than for engineers performing jobs rated as *not technical or hardly at all*. In contrast, engineers who rated their jobs as *not technical or hardly at all* rated Engineering Business competencies and Management/Leadership competencies as more important than they were rated by participants who rated their jobs as *mostly technical*. This result is consistent with a competency framework for managers in the construction industry published in 2001 (Maxwell-Hart and Marsh). In the framework the standard of technical competence required for higher level managerial jobs was lower than that required for lower level jobs which were presumably accompanied by more work involving technical detail. The result is also consistent with results in Deans' (1999) study in New Zealand in which 200 mechanical engineering graduates rated the importance of 24 knowledge-based topics and three skills for their current jobs. Deans' survey found that the rated importance of professionally-oriented subjects such as engineering economics and marketing, increased with experience, and the importance of the design process decreased.

□ Responses from Participants Who Rated their Jobs as Not Technical or Hardly At All (n = 28)

■ Responses from Participants Who Rated their Jobs as Partly Technical (n = 130)

■ Responses from Participants Who Rated their Jobs as Mostly Technical (n = 142)

* Univariate significance across sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 17. Generic engineering competency factor importance rating means (+SE) by the extent to which the participant's job was technical, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4. Key Responsibilities, and Tasks

For each of the eight key responsibilities, a MANOVA was used to test for significant variance, in the eleven competency factor importance ratings, between participants who did and did not have the key responsibility. MANOVAs were also used to test for

interaction with the two variables that had been found to be potential confounders. No significant ($p < 0.05$) interaction was found between any key responsibility and either whether a participant's secondary education was completed in Australia, or whether a participant had a bachelor of engineering from UWA. Only significant and useful results are presented. Most results for key responsibilities supported results for the various categories of tasks, and are therefore presented together with these. As noted in Chapter 5, several of the questions on work context, including that on key responsibilities, were adapted from a survey by APESMA and EA (2005).

For each of the twelve categories of tasks, a MANOVA was used to test for significant variance, in the eleven competency factor importance ratings, between participants who performed at least half of the tasks in the category to do their jobs well and those who did not. Caution in using the results is required because Levene's Test was not always satisfied. Significant differences in the factor importance ratings were found for all categories of tasks.

MANOVAs were also used to test whether there was interaction between performance of tasks and either whether a participant's secondary education was completed in Australia or whether a participant had a bachelor of engineering from UWA. No significant ($p < 0.05$) interaction was found with whether the participant completed secondary education in Australia. Whether a participant performed the teaching category of tasks interacted with whether a participant had a bachelor of engineering from UWA. However, there was no interaction for competency factors found to have significantly different importance ratings for participants performing tasks in the teaching category.

As noted in earlier chapters, the tasks within each category were adapted from the *National Generic Competency Standards: Stage 2 for Professional Engineers*

(IEAust 1999b) required for chartered membership of Engineers Australia. The task inventory was in Section IV of the questionnaire (Appendix X).

8.3.4.1. Design

For Survey 1 participants involved in design, Applying Technical Theory, Practical Engineering, and Creativity / Problem-Solving had higher factor importance ratings than for other participants.

Two key responsibilities and two task categories related to design. The four sample groups with participants most involved in these design activities shared higher factor importance ratings for Creativity / Problem-Solving, Applying Technical Theory, and Practical Engineering. For participants with the key responsibility, design of equipment/processes (not including product design), the Communication Factor also had a higher rating than for other participants. For the planning and design category of tasks, Contextual Responsibilities was the additional competency factor with a higher importance rating. For the research/development (including product design/development) key responsibility and the research/development/commercialisation category of tasks, Innovation was an additional competency factor with a higher importance rating. The results for each of these follow.

8.3.4.1.1. Key Responsibility Design of Equipment/Processes (Not including Product Design)

The multivariate test was significant for variance of the competency factor importance ratings across participants with and without design of equipment/processes as a key responsibility (Pillai's Trace = 0.12, $F(11,288) = 3.40$, $p < 0.01$, partial $\eta^2 = 0.12$). Creativity / Problem-Solving, Applying Technical Theory, Practical Engineering and

Communication factor importance ratings were higher for participants with design of equipment/processes as a key responsibility (Figure 18).

□ Responses from Engineers With Design of Equipment/Processes as a Key Responsibility (n = 111)

■ Responses from Engineers Without Design of Equipment/Processes as a Key Responsibility (n = 189)

* Significant variance between sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 18. Generic engineering competency factor importance rating means (+SE) by whether design of equipment/processes was a key responsibility, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.1.2. Planning and Design Task Category

The multivariate test for variance in the eleven factor importance ratings across participants performing at least half of the planning and design tasks, and other participants, was significant (Pillai's Trace = 0.14, $F(11,288) = 4.14$, $p < 0.01$, partial $\eta^2 = 0.14$). Competency ratings made by participants performing at least half of the tasks in the planning and design category reflected significantly higher factor importance ratings for Practical Engineering, Applying Technical Theory, Creativity / Problem-Solving, Communication, and Contextual Responsibilities (Figure 19).

□ Responses from Engineers Who Performed at Least Half of the Planning and Design Tasks (n = 163)

■ Responses from Engineers Who Performed Fewer than Half of the Planning and Design Tasks (n = 137)

* Significant variance between sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 19. Generic engineering competency factor importance rating means (+SE) by whether the participant performed planning and design tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

**8.3.4.1.3. Key Responsibility Research and
Development (including Product Design and
Development)**

The multivariate test indicated significant variance in the importance of the eleven factors, between participants who did and did not have research and development (including product design and development) as a key responsibility (Wilk's $\lambda = 0.79$, $F(11,288) = 7.02$, $p < 0.01$, partial $\eta^2 = 0.21$). The univariate tests indicated significant variance for six generic engineering competency factor importance ratings. Creativity / Problem-Solving, Applying Technical Theory, Practical Engineering and Innovation competencies were rated as more important by participants with research and development as a key responsibility than by other participants. Management/Leadership and Engineering Business were rated as less important for their work by those with research and development as a key responsibility than by other participants (Figure 20).

□ Responses from Engineers With Research and Development as a Key Responsibility (n = 70)

■ Responses from Engineers Without Research and Development as a Key Responsibility (n = 230)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 20. Generic engineering competency factor importance rating means (+SE) by whether research and development was a key responsibility, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.1.4. Research/Development/ Commercialisation

Task Category

The competency factors with significantly higher factor importance ratings for participants performing at least half of the research/development/commercialisation

tasks (Figure 21) (Wilk's $\lambda = 0.82$, $F(11,288) = 5.82$, $p < 0.01$, partial $\eta^2 = 0.18$) were similar to those above for participants with research and development as a key responsibility.

Figure 21. Generic engineering competency factor importance rating means (+SE) by whether the participant performed research/development/commercialisation tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.2. Problem-Solving

For Survey 1 participants involved in problem-solving, the factors: Creativity / Problem-Solving, Practical Engineering, Innovation, Contextual Responsibilities, Management/Leadership and Engineering Business, all had higher factor importance ratings than for other participants.

Three task categories related most directly to problem-solving. These were the change / technical development task category, the engineering practice task category, and the investigation and reporting task category. The three sample groups with participants most involved in these categories of tasks shared higher factor importance ratings ($p < 0.05$) for Creativity / Problem-Solving, Practical Engineering, Innovation, Contextual Responsibilities, Management/Leadership and Engineering Business.

This is consistent with engineers solving problems that are both technical and also embedded within management and business contexts. The conclusion from the responses to open questions at the beginning of the survey is supported: that engineering business is an important area of engineering competence, one which engineers could promote as part of their professional images (Male *et al.* 2010a) (Appendix XX). Results for each of the relevant task categories follow.

8.3.4.2.1. *Change / Technical Development (e.g. Improvement of Products or Services Provided by Participant's Organization) Task Category*

Competency importance ratings from participants performing at least half of the change / technical development tasks indicated significantly higher ($p < 0.01$) factor importance ratings than indicated by other participants' responses, for seven competency factors (multivariate test Wilk's $\lambda = 0.86$, $F(11,288) = 4.45$, $p < 0.01$, partial $\eta^2 = 0.14$) (Figure 22). The only other categories of tasks for which this occurred were the

engineering practice category, and the materials/components/systems or sourcing of materials/components/systems category.

Figure 22. Generic engineering competency factor importance rating means (+SE) by whether the participant performed change / technical development tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.2.2. Engineering Practice Task Category

The engineering practice tasks included: identifying opportunities for engineering solutions, forming teams, developing solutions, identifying constraints and publishing outcomes. All but one of the competency factor importance ratings reflected by competency ratings from participants who performed at least half of the tasks in this category were significantly higher than reflected by other participants' responses (multivariate test Pillai's Trace = 0.19, $F(11,288) = 6.17$, $p < 0.01$, partial $\eta^2 = 0.19$) (Figure 23). The most significant variances between the two sample groups were for the Management/Leadership Factor, the Practical Engineering Factor, and the Creativity / Problem-Solving Factor.

□ Responses from Engineers Who Performed at Least Half of the Engineering Practice Tasks (n = 192)

■ Responses from Engineers Who Performed Fewer than Half of the Engineering Practice Tasks (n = 108)

* Significant variance between sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 23. Generic engineering competency factor importance rating means (+SE) by whether the participant performed engineering practice tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.2.3. Investigation and Reporting Task Category

Engineering Business, Management/Leadership, Contextual Responsibilities, Innovation, Practical Engineering, Creativity / Problem-Solving, and Self-Management had factor importance ratings that were significantly higher for the participants performing at least half of the investigation and reporting tasks than for other participants (multivariate test Wilk's $\lambda = 0.90$, $F(22,574) = 2.77$, $p < 0.01$, partial $\eta^2 = 0.10$) (Figure 24).

□ Responses from Engineers Who Performed at Least Half of the Investigation and Reporting Tasks (n = 232)

■ Responses from Engineers Who Performed Fewer than Half of the Investigation and Reporting Tasks (n = 68)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 24. Generic engineering competency factor importance rating means (+SE) by whether the participant performed investigation and reporting tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.3. Sales/Marketing

For Survey 1 participants involved in sales and marketing, Professionalism, Innovation and Working in Diverse Teams had higher factor importance ratings than for other participants.

Participants with the key responsibility sales/marketing and participants performing at least half of the tasks in the technical sales/promotion category shared three factors for which they rated the competencies more important than did other participants. These factors were Professionalism, Innovation and Working in Diverse Teams.

8.3.4.3.1. Key Responsibility Sales/Marketing

The multivariate test for variance in the eleven competency factor importance ratings between participants with and without the key responsibility sales/marketing, was significant (Pillai's Trace = 0.16, $F(11,288) = 4.80$, $p < 0.01$, partial $\eta^2 = 0.16$).

Univariate tests were significant for the factor importance ratings for Professionalism, Innovation and Working in Diverse Teams (Figure 25).

□ Responses from Engineers With Sales/Marketing as a Key Responsibility (n = 31)

■ Responses from Engineers Without Sales/Marketing as a Key Responsibility (n = 269)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 25. Generic engineering competency factor importance rating means (+SE) by whether sales/marketing was a key responsibility, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.3.2. Technical Sales/Promotion Task Category

Although the factor importance ratings for seven competency factors were significantly higher for participants performing at least half of the technical sales/promotion tasks than for other participants (multivariate test Wilk's $\lambda = 0.820$, $F(11,288) = 5.55$,

$p < 0.01$, partial $\eta^2 = 0.18$), surprisingly the Communication Factor was not among these (Figure 26). This reflects the high importance of communication to engineering jobs on average.

Figure 26. Generic engineering competency factor importance rating means (+SE) by whether the participant performed technical sales/marketing tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.4. Teaching

The key responsibility teaching/training and the teaching task category both related to teaching. The multivariate test for variance in the eleven competency factor importance ratings across participants with and without teaching/training as a key responsibility was insignificant (Wilk's $\lambda = 0.96$, $F(11,288) = 0.99$, $p = 0.46$, partial $\eta^2 = 0.04$). However, this was not the case for the teaching task category.

8.3.4.4.1. Teaching Task Category

The multivariate test for variance in the eleven competency factor importance ratings between participants who were and were not performing at least half of the teaching tasks was significant (Wilk's $\lambda = 0.91$, $F(11,288) = 2.45$, $p < 0.01$, partial $\eta^2 = 0.09$).

Three competency factor importance ratings were higher for participants performing at least half of the teaching tasks than for other participants. Management/Leadership, rather than Communication, was one of the three (Figure 27).

□ Responses from Engineers Who Performed at Least Half of the Teaching/Training Tasks (n = 30)

■ Responses from Engineers Who Performed Fewer than Half of the Teaching/Training Tasks (n = 270)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 27. Generic engineering competency factor importance rating means (+SE) by whether the participant performed teaching/training tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.5. Other Management Related Responsibilities and Tasks

8.3.4.5.1. Construction Supervision

(Key Responsibility)

The multivariate test for variance in the competency factor importance ratings across participants with and without construction supervision as a key responsibility was significant (Pillai's Trace = 0.11, $F(11,288) = 3.30$, $p < 0.01$, partial $\eta^2 = 0.11$). The Applying Technical Theory Factor importance rating was significantly lower for participants with construction supervision as a key responsibility than for other participants and the Management/Leadership Factor importance rating was significantly higher (Figure 28). This result was consistent with differences in competency factor importance ratings for work in rural, remote and offshore locations (Figure 14).

□ Responses from Engineers With Construction Supervision as a Key Responsibility (n = 52)

■ Responses from Engineers Without Construction Supervision as a Key Responsibility (n = 248)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 28. Generic engineering competency factor importance rating means (+SE) by whether construction supervision was a key responsibility, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.5.2. Project Engineering / Engineering Project

Management Task Category

Participants performing project engineering and engineering project management rated a broad range of competencies as more important than other participants

(Pillai's Trace = 0.18, $F(11,288) = 5.57$, $p < 0.01$, partial $\eta^2 = 0.18$). The factor importance ratings for Engineering Business, Management/Leadership, Contextual Responsibilities, Practical Engineering, Communication, Innovation, and Creativity / Problem-Solving reflected by responses from participants performing at least half of the project engineering or engineering project management tasks were significantly higher than those reflected by other participants (Figure 29). These are the same factors that had higher factor importance ratings for the participants performing more of the problem-solving activities than other participants (section 8.3.4.2).

- Responses from Engineers Who Performed at Least Half of the Project Engineering / Project Engineering Management Tasks (n = 144)
 ■ Responses from Engineers Who Performed Fewer than Half of the Project Engineering / Project Engineering Management Tasks (n = 156)

* Significant variance between sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 29. Generic engineering competency factor importance rating means (+SE) by whether the participant performed project engineering / engineering project management tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.5.3. *Environmental Management Task Category*

Responses from participants performing at least half of the environmental management tasks reflected significantly higher factor importance ratings for Contextual Responsibilities, Management/Leadership, Communication, and Working in Diverse Teams than did responses from other participants (Pillai's Trace = 0.11, $F(11,288) = 3.24, p < 0.01$, partial $\eta^2 = 0.11$). The most significant variance was in the Contextual Responsibilities Factor ($F(1,298) = 23.8, p < 0.01$, partial $\eta^2 = 0.07$), with a mean importance rating of 3.6 for participants performing at least half of the environmental management tasks and 2.9 for other participants.

□ Responses from Engineers Who Performed at Least Half of the Environmental Management Tasks (n = 61)

■ Responses From Engineers Who Performed Fewer than Half of the Environmental Management Tasks (n = 239)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 30. Generic engineering competency factor importance rating means (+SE) by whether the participant performed environmental management tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.5.4. Business Management/Development Task

Category

All of the competency factors except Contextual Responsibilities and Applying

Technical Theory had factor importance ratings significantly higher ($p < 0.05$) for

participants performing at least half of the business management/development tasks

(Wilk's $\lambda = 0.82$, $F(11,288) = 5.60$, $p < 0.01$, partial $\eta^2 = 0.18$) (Figure 31).

Figure 31. Generic engineering competency factor importance rating means (+SE) by whether the participant performed business management/development tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.6. Engineering Operations Task Category

The factor importance ratings indicated that participants performing at least half of the engineering operations tasks rated a broad range of competencies as more important than other participants (Pillai's Trace = 0.13, $F(11,288) = 3.80$, $p < 0.01$, partial $\eta^2 = 0.13$). Higher factor importance ratings were reflected for Self-Management, Engineering Business, Management/Leadership, Contextual Responsibilities, Practical Engineering and, to a less significant extent, Innovation and Creativity / Problem-Solving, by responses from participants performing at least half of the engineering operations tasks than by other participants' responses (Figure 32). The engineering operations category of tasks was the only key responsibility or task category related to an increased factor importance rating at significance $p < 0.01$ for Self-Management. The other competency factors that had higher factor importance ratings for participants performing at least half of the engineering operations tasks than other participants were the same factors as for the problem-solving activities.

□ Responses from Engineers Who Performed at Least Half of the Engineering Operations Tasks (n = 50)

■ Responses from Engineers Who Performed Fewer than Half of the Engineering Operations Tasks (n = 250)

* Significant variance between sample groups

* ($p < 0.05$)

** ($p < 0.01$)

Figure 32. Generic engineering competency factor importance rating means (+SE) by whether the participant performed engineering operations tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.3.4.7. Materials/Components/Systems or Sourcing/Estimating of Materials/Components Task Category

The materials/components/systems and sourcing/estimating of materials/components category of tasks included technical and managerial tasks: determining requirements,

defining processes for preparation, estimating requirements, planning sources, and managing uses and recovery. Responses from participants performing at least half of the tasks in the category indicated significantly higher factor importance ratings for all competency factors except Innovation and Applying Technical Theory, than indicated by responses from other participants (Figure 33) (multivariate test Pillai's Trace = 0.15, $F(11,288) = 4.67$, $p < 0.01$, partial $\eta^2 = 0.15$). As for the key responsibilities and task categories listed under problem-solving, results are consistent with tasks with both managerial and technical components.

Practical Engineering was the factor with the most significant variance between its importance rating for participants who were, and were not, performing at least half of the materials/components/systems tasks ($F(1,298) = 31.8$, $p < 0.01$, partial $\eta^2 = 0.10$). For participants who were performing at least half of the tasks in the category the mean factor importance rating for Practical Engineering was 3.7 and for other participants the mean was 3.0. Based on the partial η^2 value, whether a participant performed at least half of the materials/components/systems tasks explained 10% of the variance in the factor importance rating for Practical Engineering.

- Responses from Engineers Who Performed at Least Half of the Materials/Components/Systems Tasks (n = 61)
 ■ Responses from Engineers Who Performed Fewer than Half of the Materials/Components/Systems Tasks (n = 239)

* Significant variance between sample groups * ($p < 0.05$) ** ($p < 0.01$)

Figure 33. Generic engineering competency factor importance rating means (+SE) by whether the participant performed materials/components/systems tasks, calculated from competency importance ratings made by engineers in Survey 1 (N = 300)

8.4. Discussion

The second sub-question was:

Are different generic engineering competencies important for jobs with different tasks and work contexts?

Based on the results, generic engineering competency factors are important to different extents for jobs with different tasks and work contexts. Work context variables for which there was significant variance in competency factor importance ratings included: whether the participant was working in Australia; the percentage of the participant's work time spent in rural, remote, or offshore locations; the years the participant's organization had provided its current main service or product; sector; and organization size.

There were factor importance ratings that were significantly higher for participants with specific key responsibilities and participants performing at least half of any of the twelve categories of tasks studied than for other participants.

However, causality between variables and the factor importance ratings was not tested. The results indicate that there was variance in the importance of competencies as rated by participants, across work contexts and tasks. However, the results did not show that the work context and tasks caused the variance in importance of the competencies as rated by the participants. Determining causality would require further study but was not necessary for the purposes of this research.

The results could be useful for measuring graduates' competence in the generic engineering competency factors using ratings made by workplace supervisors. To contribute to evaluation of an engineering program, it would be ideal to measure the competencies of graduates in a range of jobs in which the various competency factors are important to different extents. It might be difficult to select graduates based on their tasks. However, it could be possible to ask about the graduates' key responsibilities or

tasks in order to analyse the diversity of a sample after collecting data. In contrast, it could be possible to select a purposive sample with diversity across work contexts.

The results could be helpful for improving graduate competencies for a particular type of engineering work, or for evaluating an initiative to make such improvements.

The Contextual Responsibilities Factor was significantly higher for participants performing at least half of the environmental management tasks. This might motivate people to measure the competence of graduates from an engineering program on the Contextual Responsibilities Factor by collecting ratings of the competence of graduates working in environmental management. This would be inconsistent with the generic nature of the generic engineering competency factors. It is desirable that not only those engineers working in environmental management, but all engineers, have competence in the competencies reflected by the Contextual Responsibilities Factor.

Unfortunately, although it would be ideal to measure all competencies in all graduates, supervisors' ratings of graduates' competencies in areas of work in which the competencies are less important, are likely to be less reliable. The results presented in this chapter would help to identify jobs for which specific competence ratings could be expected to be less reliable than for other jobs. The problem would need to be assessed during any future development of an instrument to measure competencies in engineers.

Similarly, the engineers with construction supervision as a key responsibility, and those working in rural, remote and offshore locations for more of their time than other participants, indicated lower importance ratings for Applying Technical Theory. Does this mean that graduates working in these categories would not be appropriate for measurement of competence in the Applying Technical Theory Factor? The following chapter provides insight into engineers' perspectives on the generic engineering competency factors, and helps to answer this question.

8.5. *Conclusions*

At the beginning of this chapter, eleven generic engineering competency factors had been identified among the 64 competencies. These factors could be used to help evaluation and improvement of engineering education programs in Australia by collecting ratings, made by workplace supervisors, of graduates' demonstration of the competency factors. Chapter 8 has found that there is variation in the importance of generic engineering competency factors across jobs with different work contexts or tasks. Awareness of this will be important in applications such as program evaluation and development. Caution is recommended with respect to reliability of ratings of competence in jobs for which competency factors are less important than in other jobs.

CHAPTER 9. Focus Group to Validate and Refine Generic Engineering Competency Model

This chapter reports a study that used a focus group to validate and refine the generic engineering competency model previously identified from the literature review and two surveys.

9.1. *Background*

Previous phases of the study revealed an eleven-factor model of generic engineering competencies required by engineers graduating in Australia. The competencies within each factor were rated most important for similar jobs. The factors, therefore, reflect eleven job characteristics that demand particular sets of competencies or competency factors.

A proposed application of the generic engineering competency model is to collect data for evaluation of engineering education programs. An instrument could be developed to profile the success of engineering programs using measurements of individual graduates' demonstration of the eleven competency factors. Such measurements would use ratings of individual graduates' competencies made by workplace supervisors of the graduates.

The instrument could ask the following for each factor:

Based on the average performance of the graduate, how successfully does the graduate usually demonstrate this generic engineering competency factor?

1 extremely badly

2

3

4

5 extremely well

N/A – there is no opportunity for the graduate to demonstrate this competency

Competency Factor I. Communication

For example:

- using effective graphical communication (e.g. drawings)
- speaking and writing fluent English
- using effective verbal communication (e.g. giving instructions, asking for information, listening)
- communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)

Previous chapters have identified the competencies as important and Chapter 8 revealed that the factors have varying importance across jobs. For the above application, the identified competency factors would serve two purposes. Firstly, they would provide a clear, concise and comprehensive list of the generic engineering competencies that should be developed in an engineering education program in Australia. Secondly, even if it was considered necessary to collect ratings for individual competencies reflecting a factor, the competency factors would save time for the supervisors asked to rate graduates; all of the competency items reflecting a particular competency factor could be skipped if the competency factor was of too little importance in a graduate's job for the supervisor to rate.

9.2. Research Questions

The focus group was held to validate and refine the generic engineering competency model for the above application. The research questions were:

1. Do engineers consider that:
 - each competency in the model is clear
 - all of the competencies in each factor fit the factor i.e. would be most important in similar types of jobs
 - the names of the competency *factors* are clear and accurate
 - competency items in each factor comprehensively represent the factor and
 - the eleven-factor model comprehensively represents the generic competencies required by engineers?
2. If not, how can any or all of these be improved?

9.3. Methodology

Engineers will use the competency model only if they consider it to be clear and credible. Therefore, the above research questions focus on engineers' perceptions of the competency model developed in earlier stages of the Project. A focus group was used to collect engineers' opinions of the model. Focus groups are a way to interview several participants at once, and allow them to interact (Mertens 2005). Interaction between diverse participants, for example people from different levels within their organizations and from different disciplines, yielded participants' opinions and also their opinions of others' opinions.

The research questions are based on the view that different engineers will respond differently to the model. The findings of the focus group are not generalisable to all engineers but provide examples of possible responses by engineers to the model (Schofield 2002). The focus group was therefore designed to discover features of the model that could be unclear to an engineer, or could reduce the credibility of the model for an engineer, and to refine the model to improve clarity and credibility.

Another reason a focus group was appropriate was that the topic was not sensitive (Merriam 2009) and so anonymity was not necessary and the presence of other participants was unlikely to limit responses. In contrast, questions in the surveys asked engineers about their own jobs or experience, and competencies required for their jobs or jobs in their areas of experience.

9.4. Method

9.4.1. Recruitment of Focus Group Participants

Potential participants were selected to include a balance of diversity in participants' engineering positions, genders and disciplines, sizes of organizations for which participants worked, and representation from both private organizations and a government subsidised organization. Invitations (Appendix XXVI), accompanied by information sheets (Appendix XXVII), a sample consent form (Appendix XXVIII) and a description of the competencies including guiding questions (Appendix XXIX), were emailed to 20 selected potential participants, seeking availability for three potential dates. Thirteen accepted the invitation and twelve attended.

9.4.2. Demographic Details of Participants

The participants each voluntarily completed an anonymous biographical questionnaire (Appendix XXX), confirming diverse experience for which they had been selected (Table 29). Locations where participants had worked included all states of Australia, and several overseas locations: Germany, India, Malaysia, the Netherlands, Papua New Guinea, Thailand, Trinidad, the UK, and Vietnam. Industry categories were adapted from APESMA/EA survey reports (2004, 2005). Industries in which participants had worked included: appliances and electrical; basic metal products; chemical and petroleum; communication including Telstra; construction, contract, maintenance;

consulting and technical services; defence; education; electricity and gas supply; environmental engineering; fabricated metal; food, beverage and tobacco; mining or quarrying; oil/gas exploration/production; scientific equipment; water, sewerage and drainage; and transport equipment.

Engineering disciplines in which the participants were qualified were biased towards electrical and computer engineering, although civil and mechanical engineers also participated. One participant was in a senior management role, a component of which related to human resources. This participant did not nominate qualifications.

Unexpectedly, all of the participants' qualifications, except one, were gained in Australia. Greater cultural diversity and diversity among the countries where participants had studied would have provided a broader range of standpoints.

Table 29. Demographic details of participants in focus group to validate and refine the generic engineering competency model ($N = 12$)

<i>Demographic variable and values</i>	<i>Number of participants</i>
<i>Experience with graduates, and supervising engineers</i>	
Had worked with engineering graduates (within approximately five years since graduation)	12
Had supervised engineering graduates (within approximately five years since graduation)	12
Had supervised or managed engineers with more experience than graduates	11
<i>Locations in which participants had worked</i>	
Western Australia (WA)	12
Australian states other than WA	8
Countries other than Australia	9
<i>First degree</i>	
Bachelor of Engineering or equivalent	10
Bachelor of Science (Computer Science)	1
<i>Other degrees</i>	
Master of Business Administration / Master of Leadership and Management	2
Graduate Certificate (Computer Science)	1
Graduate Diploma (Structural)	1
MEngSc	1
PhD	2

<i>Disciplines in which participants were qualified</i>	
electrical/electronic/computer systems	5
civil	4
mechanical	2
geological	1

9.4.3. Focus Group Procedure

The focus group was held on 10 September 2009 at UWA. It was recorded with two video cameras, as noted in the information sheet for participants (Appendix XXVII).

The duration was an hour and a half.

Foddy (1993) recommends an explanation of the purpose of the research in order to improve reliability of results. I outlined the overarching project and purpose of the focus group, drawing attention to the information participants had already received, including background, guiding questions and descriptions of the competency factors (Appendix XXIX).

A semi-structured focus group was used. Planned guiding questions were accompanied by improvised probing questions to encourage participants to elaborate or clarify their responses. Questions with yes/no responses are discouraged in literature on interview questions because they allow minimal responses (Merriam 2009). However, such questions were included and, in the focus group setting, participants expanded upon responses and thereby countered the usual problem with yes/no questions.

Guiding Questions

- 1) For each competency factor please consider the following:
 - Is each competency clear?
 - Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?
 - Can the clarity or accuracy of the name for the competency factor be improved?

- Do the items comprehensively represent the factor?
- 2) Do the factors comprehensively represent the generic competencies required by engineers?

Participants responded to the guiding questions and discussed them. I paraphrased or asked questions where necessary to confirm understanding. I kept the discussion focused on the guiding questions, provided sufficient information about the Project to help participants understand the purpose of the discussion, and occasionally raised alternative perspectives for comment. Participants were allowed to interrupt each other and offer critical opinions of others' comments, but were always constructive. Although opinions were mainly collected from the discussion, participants were also encouraged to write responses for collection at the end.

All competency factors and descriptions were discussed, and I drew special attention to competency descriptions and factors about which other phases of the study had raised concern. For example, I noted decisions made about placement of competencies within factors, and rewording of competencies made since the original questionnaires, and reasons for these changes. I also noted competency descriptions for which there was evidence of confusion among survey participants, for example *systems approach*.

Data collected included my handwritten notes made during and immediately after the focus group, handwritten notes made by participants before and during the focus group, and transcripts and notes made while viewing the video recordings.

9.5. *Opinions Collected in Response to Guiding*

Question 1

Collected suggestions for improvements are presented in Appendix XXXI listed by competency factor and guiding question, although the discussion sometimes occurred in

a different order. The main suggestions are listed, followed by quotations that elaborate on these.

Any specific participant has a consistent letter as a label throughout any discussion on one topic but not throughout the focus group. This system was used to minimise any chance of a reader guessing a match between a participant and label.

Responses to guiding questions for which no problems or improvements were suggested are not presented.

9.6. *Opinions Collected for Guiding Question 2*

Participants had the opportunity to read the guiding questions before they arrived and attention was drawn to the questions at the beginning of the focus group. Clear themes relevant to Guiding Question 2 became apparent throughout the discussion and participants agreed upon these at the end of the focus group.

Firstly, participants found Factor IX Innovation to be confusing because it grouped competencies required for similar jobs rather than similar competencies. They supported the suggestion that the competencies in Factor IX could be spread among other factors.

Secondly, participants felt strongly that Factor XI Applying Technical Theory should be first because they considered it to be most important. “It’s a given.” “You have to have it.” “It should be number one.”

A suggestion relevant to Guiding Question 2, although not discussed at the end of the focus group, was the suggestion of a “fundamental competency” “Engineering Process”, which could be a factor. The concept encompassed any process of engineering steps which could include pre-feasibility, feasibility, and so on, or could be a design methodology, and which is slightly different in each organization. This arose during the discussions on the following factors: Applying Technical Theory, Engineering Business, and Practical Engineering.

9.7. Analysis and Discussion

The factors had been listed in order of mean rating of importance, as rated by the established engineers in Survey 1. This ordering was not consistent with the ranking of importance assumed by the focus group participants. The competency factor with the lowest mean factor importance rating in Survey 1 was Applying Technical Theory. The focus group participants considered this competency factor to be the most important, and therefore, thought that it should be Factor I. Within each factor, the competencies had been listed as in factor analysis output. It will be necessary to either re-order the competency factors and the competencies, or clearly explain the final order in which they are presented when the competency model is used.

The conversation about the competency, *using a systems approach*, in Appendix XXXI section 1.5.1, confirmed the hypothesis developed from the survey responses, that this competency was not reliably understood. The main reason this was suspected after the surveys was that the competency had been rated higher by participants in the electrical and related engineering disciplines than by other participants. It was suspected that this was because these engineers were thinking of linear and nonlinear models for systems. The focus group conversation described four different understandings: a process orientation, a goal orientation, which is related to a whole of system approach or viewing a problem in the larger context, and an understanding related to modelling. However, the focus group identified useful potential modifications to the competency descriptor, which would improve the reliability of ratings of the item, by guiding people to one of the understandings revealed during the focus group. The preferred alternative, as written by a participant on his or her copy of the guiding questions, was “a whole of systems approach (i.e. viewing a problem in the larger context)”.

Focus group participants did not feel that items in the Innovation Factor suited the factor name. The uneasiness was partly because the Innovation Factor was eclectic and therefore difficult to conceptualise as a single factor. This would also complicate measurement of a graduate's performance on this competency factor. The possible interpretation of Innovation as creativity, explained by one participant, also introduced difficulty. The participants suggested alternative factor names which better explain the competencies within the factor: "External Engagement", "Commercialising Opportunities Where Appropriate", and "Entrepreneurship".

Engineering business competency deficiencies, found among responses to open questions in Survey 1, included awareness of how engineering is done, for example the relationships between contractors, consultants and their clients, and skills in engineering work such as planning, specification, estimation, project management, cost control, risk management and maintenance management (Chapter 6, Appendix XX). These are consistent with the competencies suggested by the focus group participants for the Engineering Business Factor, and the "Engineering Process" concept described by the focus group participants.

Although no guiding question raised the issue of overall support for the Project, this was evident in the responses. There was an early question from a participant about why the Project was necessary:

Engineers Australia has Stage 1 Competencies for a degree. What was the thinking of doing this? [Participant A]

After a response from me and then from my supervisor, another participant commented:

When you try to apply the Engineers Australia competencies, there is a fair bit of overlap. [Participant B]

The discussion continued at a later stage during responses to the first guiding question, Participant A asked:

Does this relate back to what you are teaching engineering students? In the whole of engineering we never did this. We had lectures. [Participant A]

It would be great if you could get those elements into a graduate.
[Participant C]

Two participants expressed concern on several occasions, and two others noted, although without concern, that the level of competency expected was an issue: whether there was a need to define higher levels of competency that only a few graduates would have, and whether some of the competencies were too much to expect of a graduate. Participants raised the issue with respect to writing. There was agreement that persuasiveness and writing in a variety of different styles for different readerships were probably not to be expected at graduate level. The issue is important but will require further study, as noted in Chapter 12.

The participants demonstrated pleasure identifying with the technical aspect of engineering at two points in the focus group: when they laughed at the thought of expecting engineers to understand emotional intelligence, and when they discussed the Applying Technical Theory Factor. Discussing the importance of technical competencies, their faces lit up and there was much laughter. Although it was near the end of the focus group, people who had been resting their heads in their hands sat up. Everyone agreed about the factor being most important and the engineers appeared to revel in the discussion. After relating how important the competency is, one engineer said, "I get excited about this." Being excited by the importance of technical competencies is consistent with Faulkner's (2007) work in which she found engineers have a perception that real engineering is technical and working with people is not real

engineering. An expectation that engineers identify with technical engineering over entrepreneurship was suggested by the comment that engineers choose to be engineers because they are not entrepreneurs (Appendix XXXI section 1.9.1).

The discussion about the competency *having an action orientation*, quoted in Appendix XXXI section 1.3.1 was consistent with an interview response in the UK study on industry's graduate requirements (Spinks *et al.* 2006). In the CEG Project focus group discussion, it was suggested that a goal orientation was desirable and that engineering graduates often have this due to being worked so hard in their undergraduate courses and achieving the goal of surviving this. As raised in the discussion about the relatively low ratings for competencies related to science and engineering theory in section 6.5.1.2.4, the following quotation from an interview in the UK study is again consistent with the current study's data:

A potential benefit of in-depth knowledge even after the specific domain had become obsolete was that it demonstrated, as one respondent put it, "ability to master something difficult" (Spinks *et al.* 2006, p.21).

The comments from both studies suggest there is a perception, held by some industry members, that the difficulty of an undergraduate engineering program is useful preparation for engineering work.

9.8. *Refined Competency Factors*

Following is a refined competency model taking into account the opinions and suggestions made in the focus group. Changes are indicated in italics. These are recommended for the development of a survey instrument to profile the generic engineering competencies of engineering graduates using ratings made by workplace supervisors. Further testing for use in a survey would be required, especially as the additional items have not been tested.

I. Communication

- using effective graphical communication (e.g. drawings)
- speaking, writing, *and understanding* fluent English
- using effective *and persuasive spoken* communication (e.g. giving instructions, asking for information, listening)
- communicating clearly, concisely *and persuasively* in writing, *using styles appropriate to various readerships* (e.g. writing technical documents, instructions, specifications)
- *using appropriate communication technologies and etiquette*

Notes:

- Understanding was not added to the item related to writing because writing was considered a higher level competency than understanding text.
- Understanding was already implied, by *listening*, in the item related to spoken communication.
- Communicating with non-technical people and people from other disciplines was not added because this was in Factor II.

II. Teamwork

- interacting with people in diverse disciplines/professions/trades
- interacting with people from diverse cultures/backgrounds
- *interacting with people at diverse levels in organizations*
- working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)

Notes:

- *Diverse* was deleted from the factor name. The remaining name simplified to one word.
- Demonstrating humility, sharing information when appropriate, and staying informed when appropriate, were suggested and considered, but could be encompassed by the final item.

III. Self-Management

- having an action *and goal* orientation (e.g. avoiding delays, maintaining a sense of urgency *without becoming personally stressed*)
- managing personal and professional development (e.g. self-directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)
- managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance / health)
- managing information/documents
- managing his/her communications (e.g. keeping up to date and complete, following up)

IV. Professionalism

- being loyal to his/her organization (e.g. representing it positively)
- demonstrating honesty (e.g. admitting mistakes, giving directors bad news)
- being committed to doing his/her best
- presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)
- being concerned for the welfare of others (e.g. ensuring decisions are fair, facilitating *the contribution of others*)
- acting within exemplary ethical standards (*e.g. recognising conflict of interest and knowing what to do*)
- *understanding who stakeholders are*

V. Ingenuity

- thinking critically to identify potential possibilities for improvements
- sourcing/understanding/evaluating information (e.g. from co-workers /colleagues/ documents/ observations)

- thinking laterally / using creativity/initiative/ingenuity
- trying new approaches/technology / capitalising on change / initiating/driving change
- solving problems (e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs)
- being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
- using a *whole of systems* approach (*i.e. viewing a problem in a broad context*)
- using design methodology (e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating)
- *maintaining a curious attitude / questioning everything*
- *anticipating problems / being proactive*

Notes:

- The factor was previously called Creativity / Problem-Solving.
- Having an interest in industry, and solving problems in a cost-effective way are important but are relevant to the Innovation and Engineering Business Factors respectively.

VI. Management *and* Leadership

- supervising work/people
- leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)
- coordinating the work of others
- managing (e.g. projects/programs /contracts/people/strategic planning/performance/change)
- *actively managing risks*
- chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)

- making decisions or balancing trade-offs within time and knowledge constraints
- *negotiating*

Note: A version of understanding roles and responsibilities of self and others is present in the Engineering Business Factor.

VII. Engineering Business

- applying familiarity with risk/liability/legislation/standards/codes / IP issues
- applying familiarity with the different functions in his/her organization and how these interrelate
- focusing on his/her organization's needs
- *learning what is expected (e.g. when to share information)*
- *using financial understanding (e.g. internal rate of return, cash-flow, net present value, balance sheets)*
- *using commercial awareness*
- *solving problems in a cost-effective way*
- *using processes to assess project viability (e.g. prefeasibility, feasibility studies)*
- *preparing business cases / understanding what makes a business successful*
- *using basic marketing techniques*
- *working with tenders*
- *working with procurement processes*

Note: The item *learning what is expected* is likely to reduce discriminant validity, because it could reflect Professionalism, Self-Management or Teamwork.

VIII. Practical Engineering

- evaluating / advocating for / improving manufacturability/constructability/maintainability
- evaluating reliability / potential failures

- *using appropriate engineering process frameworks (e.g. feasibility, design, detailing)*
- *being familiar with documentation*
- *seeking simplicity*
- *checking frequently / assessing whether results make sense / reacting to intuitive doubt*
- *demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in his/her discipline of engineering (e.g. ability to recognise unrealistic results)*

Note: The final item was in Surveys 1 and 2 and had been removed to improve discriminant validity but the focus group participants felt that it should be included.

IX. Entrepreneurship

- engaging in entrepreneurship / innovation / identifying and commercialising opportunities
- evaluating marketing issues / applying a customer focus
- networking (i.e. building/maintaining personal/organizational networks)
- keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials / *having an interest in industry*
- presenting clearly and engagingly (e.g. speaking, lecturing)

Note: The factor was previously called Innovation.

X. Professional Responsibilities

- evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions
- being concerned for the welfare of the local, national and global communities

- evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)
- evaluating / advocating for / improving health and safety issues

Note: The factor was previously called Contextual Responsibilities.

XI. Applying Technical Theory

- applying mathematics, science or technical engineering theory, or working from first principles
- using 3D spatial perception or visualization (e.g. visualizing various perspectives)
- modelling/simulating/prototyping and recognising the limitations involved
- using research / experimentation techniques / scientific method

Note: Lifelong learning was raised in the focus group and is in the Self-Management factor.

9.9. Conclusions

The focus group revealed the level of acceptance and the concerns with which a diverse group of engineers viewed the main result of the Project, namely the generic engineering competency model. There was overall support for the model. The responses of the focus group participants raised important points to consider in the presentation of the competency model, such that it will be respected and used by members of the engineering profession in Australia. Many suggestions to improve the clarity and comprehensiveness of the competency model have been adopted in the refined version.

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CHAPTER 10. Results, Findings and Implications

Main results and findings are summarised here. Implications follow. Parts of this chapter are presented in a conference paper (Male *et al.* 2010b).

10.1. Main Results and Findings

10.1.1. Generic Engineering Competencies

The CEG Project has identified the generic engineering competencies required by engineers graduating in Australia. Using the first large-scale surveys in Australia to focus on the competencies required by established engineers across all disciplines of engineering, 64 competencies were identified (Chapters 5 and 6, Table 17). Along with in-depth technical competence in a chosen engineering field, these competencies form a comprehensive list of the competencies that engineers graduating in Australia will need for their work as established engineers.

Because the method included the first large-scale survey of its kind in Australia, the result is the first generalisable list of competencies and their perceived importance, for engineers graduating in Australia. Results confirm those of small-scale studies in Australia, and are consistent with results of large-scale surveys in the USA, Europe, and New Zealand. Attitudinal, interpersonal, practical, creative, professional, engineering business related, and entrepreneurial competencies are required in addition to the traditionally taught technical competencies. Competencies perceived as highly important related to communication, teamwork, professionalism, self-management, problem-solving, critical thinking, creativity, and practical engineering skills.

10.1.2. Eleven-Factor Generic Engineering

Competency Model

An eleven-factor model of the competencies was derived statistically rather than conceptually which is the more common approach (Table 24 and section 9.8). This established a concise, comprehensive generic engineering competency model, suitable to be used to profile competencies of graduates and help to improve engineering education programs. The method identified a competency model with factors that are more distinct than items currently stipulated for accredited engineering education programs in Australia, either in the generic attributes (EA 2005b) or the Stage 1 Competencies (EA 2005a). This will make it easier to use to profile the competencies of graduates and to improve engineering education programs.

Entrepreneurship (named “Innovation” before the focus group) was identified as a generic engineering competency factor. As noted in section 2.1, entrepreneurship is not currently explicitly stipulated as a competency that must be developed by students of accredited engineering programs in Australia. The result supports Radcliffe (2005), Ferguson (2006a) and Popp and Levy’s (2009) conclusions that engineering students should develop competencies in entrepreneurship or innovation. Although the literature uses “innovation” to refer to commercialising opportunities, the focus group revealed that this understanding is not reliable (Appendix XXXI.1.9). Therefore, “Entrepreneurship” is recommended as the generic engineering competency factor name.

Applying Technical Theory was identified as a generic engineering competency factor. Of the eleven generic engineering competency factors, it received the lowest mean factor importance rating. However, this could be because engineers are not aware when they are using this competency factor. The CEG Project’s survey results and Trevelyan’s (2007) findings suggested that engineers do not always realise when they

are using their understanding of technical engineering (section 6.5.1.2.4). The focus group discussion indirectly supported this explanation for the low Applying Technical Theory competency ratings. The focus group participants saw the Applying Technical Theory Factor as the most important generic engineering competency factor, particularly *applying mathematics, science or technical engineering theory or working from first principles* (sections 9.6 and 9.7, and Appendix XXXI section 1.11.1). The discussion revealed that one of the reasons this was essential was to recognise whether a proposed solution was physically possible. A design with water flowing uphill without a pump was an example provided by a focus group participant. In the examples discussed in the focus group the implication was that the engineers needed a strong understanding of fundamental mathematics, science and technical engineering theory. To overcome the criticisms made by the focus group participants in their examples, engineers would have needed to be so familiar with first principles that these felt innate. Then it would be instantly obvious when a solution was impossible. This would explain established engineers not realising when they are using first principles of mathematics, science and engineering theory.

Regardless of the reason for the relatively low survey ratings for the competencies reflecting the Applying Technical Theory Factor, the focus group confirmed the importance of this Factor. The Factor is central to an engineer's credibility and value.

A result of the large-scale surveys, which is also supported by comments from the focus group, is that fundamental competencies in fields of engineering outside an engineer's discipline were identified as useful. *Interacting with people in diverse disciplines/professions/trades* was rated critical by 58% of Survey 1 participants, which was the second highest percentage for any competency (section 6.5.1.1). In the focus group, electrical/electronic engineers provided examples to demonstrate the importance of a sound understanding of first principles, and one example referred to pumping water

and the other referred to gas laws (Appendix XXXI section 1.11.1). These are examples of cases when it was important for an engineering graduate to be familiar with first principles outside his or her engineering discipline.

10.1.3. Method to Identify Generic Competencies for a Profession

The research developed a rigorous method for identifying generic competencies required by graduates for a specific profession. The method takes advantage of previous studies. It also takes into account the complexities of competencies, identified by the DeSeCo Project (OECD 2002): that competencies encompass knowledge, skills, attitudes and dispositions, are interrelated and manifested in response to demands, and exist as constellations with varying relative importance across contexts. By focusing on established engineers rather than graduates, the method recognises that competencies are developed over time. The method also accommodates the broad range of jobs performed by engineers. Using large-scale surveys allowed generalisation of results. By collecting data about participants' jobs it was possible to reveal variation in the relative importance of competencies across jobs.

10.1.4. The Nature of Competencies

The CEG Project methodology was based on the DeSeCo theoretical framework for understanding competencies (section 1.7.1.2) (OECD 2002). The research demonstrated that, although not specifically designed for engineering, the DeSeCo framework for understanding competencies can be applied to competencies required by engineers. Results particularly supported two features of the DeSeCo framework, discussed below.

The results revealed variation in the importance of generic engineering competencies across job characteristics: tasks and work contexts (Chapter 8). This is consistent with the DeSeCo framework's description of competencies as existing in constellations with

relative importance varying across contexts. As discussed in section 1.7.2, this is also consistent with the framework developed by the *Educating Engineers for the 21st Century* study, which conceptualised three identifying roles of engineers as “technical experts”, “integrators” and “change agents” (Spinks *et al.* 2006, p.5).

Several steps were necessary to refine the competency model to achieve discriminant validity among the generic engineering competency factors (section 7.3.2). This difficulty is consistent with the interrelated nature of competencies that is described by the DeSeCo framework for conceptually understanding competencies (OECD 2002) discussed in section 1.7.1.2.

10.1.5. Generic Competencies are “Flavoured” for Engineering

Further considering the interrelated nature of competencies, the CEG Project was designed with a theoretical framework which did not separate competencies that are generic to many types of work from engineering-specific competencies (section 1.7.2). Although a methodology is likely to identify results that are consistent in nature with the adopted theoretical framework, this is not inevitable. The competency factors were identified statistically using the competency importance ratings. Therefore, it is informative for competency theory, that the identified competency factors encompassed engineering-specific and more generic elements within individual factors. For example, the eleven-factor competency model identified by this research includes *Engineering Business*, and comments made in the focus group agreed that engineering business rather than generic business competencies are required by engineers. Similarly, the Ingenuity Factor (originally called the Creativity / Problem Solving Factor) includes not only *problem-solving* and creativity but also *systems*, which is an engineering-specific element. As a final example, the Communication Factor includes *graphical communication*, which might not be assumed to be a necessary part of communication

for all professions. These examples imply that engineers require an engineering version of the competencies that are often called “generic” due to their relevance to many types of employment.

Some universities have assumed that generic competencies could have different forms in different faculties (Barrie 2006). However, this is not a common assumption.

Implications for teaching and learning are discussed in section 10.2.4.

10.1.6. Perceived Competency Deficiencies

Responses to the first two questions in Survey 1 were used to discover the competencies that engineers perceived to be deficient in engineering graduates (Appendix XX) (Male *et al.* 2010a). The method was unusual because it used open questions in a large-scale survey. Practical engineering, engineering business competencies, communication skills, self-management and appropriate attitude, problem-solving, and teamwork featured among perceived competency deficiencies. Implications are discussed in section 10.2.1.

10.1.7. Engineers’ Identities

The research unintentionally collected data with implications about engineers’ identities. In the focus group (Chapter 9), participants were excited by technical competencies and fundamental science, and a participant declared that one of the reasons students choose to be engineers is to avoid being entrepreneurs. The identification with technical work must be a motivator for commitment to performing technical work well.

Section 10.1.2 discussed the importance of the Applying Technical Theory Factor, and particularly, *applying mathematics, science or technical engineering theory or working from first principles*. Another theme in the data is that understanding of mathematics, science and engineering theory was seen by panel session and focus group

participants as critical to gaining respect within the engineering profession. A participant in the panel session on tasks performed by engineers working in research and development (Chapter 4) commented that an engineer must have in-depth technical knowledge in at least one field in order to gain credibility necessary to be successful. Other participants in the panel session agreed with this view. Referring to the more fundamental level of technical understanding, in the focus group to refine the eleven-factor generic engineering competency model (Chapter 9), participants laughed about the foolish mistakes that graduates can make if they do not have sufficient understanding of first principles to recognise unrealistic assumptions or solutions (Appendix XXXI section 1.11.1). These comments are consistent with the first three elements of the first unit of competence of the Stage 1 Competency Standards, namely *PE 1.1 Knowledge of science and engineering fundamentals*, *PE 1.2 In-depth technical competence in at least one discipline* and *PE 1.3 Techniques and resources*. Particularly relevant among the indicators of the third element is, “ability to verify the credibility of results achieved, preferably from first principles” (EA 2005a, p.5).

Although there are benefits for technical performance related to engineers taking pride in performing well technically, the technical emphasis within engineers’ identities raises concerns about engineers’ attitudes towards engineering work that is not seen as part of the identity. Competencies that are important but are not part of the identity could be marginalised by engineers, engineering educators, students, and prospective students.

This problem has been recognised by other researchers. Faulkner (2007) found that engineers identify with technical work and not work that is perceived to be non-technical, although their work actually combines technical work with other work. Similarly, Fletcher (1999) found that in a consulting engineering firm, work related to relationships was important to the success of projects but not recognised as part of engineering work.

10.1.8. Gender Typing in Engineering

The research included the first large-scale quantitative study to have revealed under-rating of stereotypically feminine competencies that are required by engineers, among a sample of engineers (Male *et al.* 2009c, Male *et al.* 2009b). Similar phenomena had previously been measured in large-scale quantitative studies in management (Schein *et al.* 1996) but not in engineering. However, other studies, such as Gill *et al.*'s (2008), have made related findings in engineering, as discussed in Appendix XXXII.

To gender type is to subconsciously use a gendered prototype of the ideal person for a job. Analysis of the male engineers' competency ratings made in the two surveys revealed results consistent with gender typing of engineering jobs among the senior male engineers in the second survey. The study is presented in Appendix XXXII, including implications and recommendations. An outline follows.

A reference group of people with relevant expertise rated the competencies on stereotypical gender as perceived by professionals in Australia. Among the Survey 1 and 2 responses, stereotypically feminine competencies were more likely than stereotypically masculine competencies to be under-rated by the senior engineers in the second survey, compared with the ratings by the male engineers in the first survey.

Participants in the first survey were asked about their own jobs and were therefore less likely to rely on subconscious prototypes than participants in the second survey, who were asked about jobs of typical engineers.

The finding relates to senior male engineers only, because the method allowed measurement of the phenomenon among this group of participants. Firstly, only senior and not established engineers participated in Survey 2. If established engineers had completed Survey 2, then any presence of the phenomenon among established engineers could have been investigated, but this was not the case. Secondly, too few female

engineers participated in Survey 2 to compare ratings among female participants across the surveys.

The under-rating of important stereotypically feminine competencies among senior engineers has concerning implications. Development of important stereotypically feminine competencies could be undermined within engineering education by the phenomenon. The phenomenon could bias recruitment and promotion practices. The phenomenon could also be linked to identity conflict experienced by female and feminine engineering students and engineers.

10.2. *Implications*

10.2.1. For Engineering Educators

The results will help engineering educators to improve engineering education in Australia by aligning the competencies that they help students to develop with the competencies required for engineering jobs.

As discussed in Chapter 9, this study was designed such that results could be used to profile the competencies of graduates of engineering programs using ratings made by workplace supervisors of graduates, and thereby help to improve engineering education. This could also be used for benchmarking purposes.

Additionally, a proactive approach to improving education is advocated by Biggs (2003, pp. 267-269), who calls for “prospective quality assurance”, or “quality enhancement”, rather than “retrospective quality assurance”. He asserts that “constructive alignment” between curriculum, teaching, assessment, classroom climate and institutional climate is necessary to encourage deep learning (p.26). Steps to improve this alignment could be taken using the results of the CEG Project.

The eleven-factor generic engineering competency model includes competencies that are likely to be best developed and assessed using innovative methods to complement

traditional lectures, tutorials, laboratory sessions, and examinations. Similarly, addressing the perceived competency deficiencies in engineering graduates (section 6.4 and Appendix XX) will require teaching and learning methods and environments beyond traditional lectures and laboratory sessions. Problem-based and project-based learning, practical experience, interaction with industry, teamwork, project management experience, and formative assessment, will be required to complement traditional methods, in order to develop many of the competencies identified by the CEG Project.

The attitudinal competencies that were identified as important are likely to be developed by example. Walther and Radcliffe found that students develop attitudinal competencies and inappropriate attitudes for work from aspects of the learning environment such as the prevailing culture and the academics' characters (Walther and Radcliffe 2007). Therefore, engineering educators must demonstrate commitment to doing one's best, honesty, ethics, loyalty, and concern for safety and the welfare of others. Interaction with industry must be strategic.

10.2.1.1. Program Structure

There is a diverse range of engineering program structures in Australia (Johnston *et al.* 2008). These include four-year programs with vacation experience, five-year sandwich programs with industry placements, and combined degrees with other programs such as science, arts, law, and commerce. The Bologna Process in Europe has highlighted the issue of program structure in Australia (King 2007). The University of Melbourne has changed to a 3+2 structure and UWA will change to a similar structure in 2012 (Smith and Hadgraft 2007). In this structure students will complete a master of engineering after a general three-year degree such as a bachelor of science.

Program changes, such as this, raise important questions about how engineering programs should be structured, and the CEG Project's findings can contribute to the

debates. The recommendations suggest advantages and disadvantages for various strategies and, therefore, help to balance the trade-offs in decisions rather than directing decisions.

The participants' perception that engineers gain from fundamental competencies in disciplines of engineering outside their specialty supports program structures that give students general engineering competencies before they specialise.

The participants' perception that competencies in fundamental science, mathematics and technical engineering theory were important, supports development of strong foundations in these areas. For these to be so well understood that they become second nature to the engineering students, students will need to practise applying the fundamental concepts in multiple ways, preferably including practical experience.

The interrelated nature of the generic engineering competencies, and the embedded combination of generic graduate competencies and engineering-specific competencies within the generic engineering competency factors, suggests that students need opportunities to develop all generic engineering competencies: generic and engineering-specific, within an engineering framework. The conclusion that competencies perceived as generic are best taught in an engineering context, is supported by a review of literature, presented in Appendix XXXIII, on generic engineering competencies required by engineers. Therefore, teaching methods and learning opportunities that develop generic competencies within an engineering framework are recommended. Problem-based and project-based learning are examples of methods that can achieve this. Strategic curriculum design can also help to achieve the goal (McGregor *et al.* 2000, Dowling 2009).

One of the generic engineering competency factors identified by the CEG Project is Practical Engineering. Practical engineering competencies were also found to be among graduate competency deficiencies perceived by engineers. Therefore, ways to improve

these must be considered. Active learning opportunities, such as problem-based and project-based learning and peer tutoring, are recommended (Cameron 2009).

Engineering educators should design their programs with an understanding that diverse programs and diverse graduates are desirable because different jobs place different importance on the generic engineering competencies (Chapter 8). This is one reason that engineering educators should seek to recruit a diverse range of students. Flexibility within programs, or at least diversity among programs, is also recommended.

10.2.1.2. Engineering Culture and Non-Technical Competencies

Engineering educators must give their students a realistic understanding of engineering work and the competencies required by engineers, recognising the significance of work and competencies that are not obviously technical and competencies that are stereotypically feminine. Engineering educators must be careful not to undermine the importance of competencies by accidentally implying that they are not important through actions or communication.

Engineering educators must be careful to give non-technical and stereotypically feminine competencies sufficient status in their teaching and students' learning, and to assess students' demonstration of competencies without bias that either under-rates the importance of these competencies, or under-rates female students.

Engineering educators should help their students to be aware of the possibility that engineers and students can easily make subconsciously biased decisions due to the culture of engineering. Adapting a feature of inclusive science curricula from Rennie (2005), in inclusive engineering curricula students should have an opportunity to learn about culture, stereotypes and myths around engineering. However, it is likely that introduction to the possibility of an engineering culture, rather than an understanding of the culture, might be as much as can be achieved among engineering students.

Jolly (1996) found that the most common approach adopted by female engineering students in her study, to survive the masculine culture, was to outwardly condone it. This strategy conflicts with recognising that the culture exists. Pragmatically, engineering educators must plant the idea of culture so that students can later develop understanding. Engineering educators should at least recognise when subconscious bias could be occurring.

10.2.2. For Engineering Education Policy Makers

Changes to engineering education in Australia are partly driven by the program accreditation criteria stipulated by Engineers Australia (EA 2005b). The Australian Learning and Teaching Council (2010) is supporting development of Learning and Teaching Academic Standards for the Tertiary Education Quality and Standards Agency. Based on the CEG Project, implications and recommendations with respect to engineering program accreditation or quality assurance in Australia are listed below:

- The expansion of curricula beyond the technical competencies traditional to engineering education, as recommended by Engineers Australia, is supported by the personal, interpersonal, business and attitudinal elements among the competencies identified as important by the Project. Technical competencies remain essential.
- The broadly-defined nature of the recommended competencies, allowing for variation between programs, is supported by the results of Chapter 8, which demonstrate that the importance of competencies varies across jobs.
- The encouragement of innovative teaching practices and learning opportunities beyond lectures and laboratory sessions is further supported by the CEG Project, as discussed above in the recommendations for engineering educators.
- The eleven-factor generic engineering competency model identified by the CEG Project could be considered as a more useful model, than that currently used for

accreditation, due to its discriminant validity, although familiarity with the existing criteria is a factor in their favour.

- Entrepreneurship should be considered as an additional competency area that must be developed by students of accredited engineering programs in Australia.
 - Although working in diverse teams is important as a generic engineering competency, “teamwork” which implies diverse and also homogenous teams would be a better competency to stipulate (Appendix XXXI.1.2 and section 9.8).
 - *Using a systems approach* is not reliably understood (Appendix XXXI.1.5) and therefore requires additional explanation if it is to be stipulated in accreditation criteria.
- Engineers Australia’s holistic assessment of competencies is further supported by the CEG Project, which confirmed the interrelated nature of competencies.
 - Policies to ensure that decisions such as development of competency models, assessment of individuals, and accreditation of programs are made with care to avoid subconscious bias against stereotypically feminine traits, are supported by the CEG Project.
 - Engineers Australia’s initiatives that highlight leadership, diversity, and community service are supported by the CEG Project. The Project results confirm that members of the engineering profession have more to celebrate than technical expertise and should identify with broader competencies. While technical expertise is critical, engineering work requires personal competencies, interpersonal competencies, leadership, and *engineering* business competencies, and engineers have concern for the community, the environment, and workers.

10.2.3. For Engineers and Engineering Students

Based on the CEG Project results and findings, the following recommendations are made. Engineers and engineering students should:

- consciously develop the eleven generic engineering competency factors
- identify with and be proud of all of the competencies required by engineers, not just the technical ones
- understand that generic engineering competencies vary in importance across jobs, and therefore, take opportunities to find out about a variety of jobs and select jobs to which their competency profiles are suited and develop competencies for desired jobs
- take care to question their assumptions about the importance of competencies, especially when making high stake judgements such as selection and promotion decisions
- be aware of the potential for subconscious bias due to the gendered nature of engineering and society, and recognise and name it, rather than individualising it and accepting its consequences

10.2.4. For People with an Interest in Educational Theory

The CEG Project has developed a method to identify generic competencies required by graduates for a profession. The Project has demonstrated that the conceptual framework for understanding competencies developed by the DeSeCo Project (OECD 2002) can be applied to engineering. As understood by the framework, the identified generic competencies were interrelated and their importance varied across job tasks and work contexts.

Competencies that are generic across professions took on engineering-specific versions to become generic engineering competencies. Therefore, the assumption that generic competencies are so generic they are the same for all jobs should be questioned.

10.2.5. For Prospective Engineering Students and their Advisors

People considering studying engineering and working as engineers must understand that engineering requires more than scientific theory and mathematics. Communication, teamwork, self-management, responsible attitudes, leadership, engineering business competencies, and entrepreneurship are also important.

Prospective students and their advisors should be aware that there is a broad range of engineering jobs available to engineers graduating in Australia and the relative importance of generic engineering competencies varies across jobs. Therefore, prospective students should take opportunities to find out about a variety of engineering jobs.

CHAPTER 11. Reflections on Method

One of the significant original contributions of this research has been the development of a method to identify the competencies that graduates will need in their jobs, despite the variety of these jobs. The need to improve and evaluate education programs exists in contexts other than engineering education in Australia, for example other disciplines and other countries. The following reflections on the successful features, limitations, and potential improvements of the method might assist future studies including those in other contexts.

11.1. *Successful Features of the Method*

The quantitative methods used in this study achieved generalisable results that will help to improve engineering education. Large-scale surveys, designed to maximise validity and reliability as described in Chapter 5, made possible the contributions listed in section 10.1. The research has identified generic engineering competencies and the perceived importance of the competencies.

Important features of Survey 1 include:

- taking advantage of the broad range of literature on engineering education, higher education, and competencies for life
- testing the questionnaire, particularly to refine the online implementation
- focusing engineers on their work, before asking them to rate the importance of competencies, to reduce subconscious bias
- asking engineers to rate their own work rather than generalising, also to reduce subconscious bias

The focus group (Chapter 9) also proved to be a part of the Project with important understanding that complemented the surveys. For example, the focus group discussion revealed the importance of technical competence to the participants. It also revealed that

participants perceived success in an engineering education program to indicate that a graduate has the goal orientation necessary for engineering.

11.2. *Implications of the Method*

11.2.1. Implications of the Scope

As discussed in section 1.7.1.4.1, the responsibility to help students develop competencies required for engineering work is only one of the responsibilities of engineering educators. Others include helping students to develop competencies to contribute to society and for their lives outside work. Competencies outside the scope of the CEG Project must be considered, along with the competencies identified in this research, to improve engineering education.

11.2.2. Implications of the Data Gathering Methods

The theoretical perspective provided by the DeSeCo Project warns of different stakeholders' perspectives on which competencies are important and the final focus group in this Project revealed how easily words are interpreted differently by different people. By asking engineers to rate the importance of competencies to doing their current jobs well, Survey 1 collected relatively low ratings for technical theory and competencies related to sustainability. Competencies in these two categories receive varied ratings of importance in the literature (Appendix XXXIII.4.2.3). These competencies are important, as demonstrated by their stipulation in engineering education program accreditation criteria. Studies asking different stakeholders such as community members, or studies asking about competencies for engineering careers, rather than current jobs would glean different results, probably with higher ratings for theoretical understanding and for competencies related to sustainability, the society and the environment.

11.2.3. Implications of the Analysis Methods

The eleven-factor competency model was identified, from the Survey 1 importance ratings for the 64 competencies, using exploratory factor analysis. This grouped competencies with correlated ratings. All of the factors made conceptual sense when this was considered, because the competencies indicating each factor were competencies that would be most important in similar jobs. The competencies reflecting most factors were obviously similar. For example, the competencies in one factor all related to communication, and the competencies in another related to teamwork. The factor originally called Innovation, and renamed Entrepreneurship after the focus group, was the most eclectic factor, including *entrepreneurship*, *keeping up to date*, *marketing*, *networking*, and *presenting*. As noted by a focus group participant, these were all related to external engagement.

This highlights an important implication of the method used to identify the factors in the eleven-factor model. The factors represent competencies that are likely to be most important in similar jobs, and not necessarily factors that are likely to be developed at the same time by a student.

11.3. Limitations

The use of surveys limited the depth of understanding, about how engineers perceive competencies, that could be investigated. People will have different conceptual understanding of competencies, just as Barrie identified different conceptual understanding of generic attributes. The research achieved useful results while recognising this issue. The issue could affect how people use the results. Qualitative research similar to Barrie's work on generic attributes could be used to investigate the issue. As noted (section 11.1), the focus group complemented the surveys well.

11.4. *How the Method Could Have Been Improved*

Samples for the panel session (Chapter 4) and the focus group (Chapter 9) were selected for diversity, as noted in the chapters. However, as noted in Chapter 9, the focus group participants had all studied in Australia. Better cultural diversity could have increased the breadth of responses.

Samples for Surveys 1 and 2 were sufficiently large to achieve the necessary statistical power, and the analysis of the demographics of the survey participants demonstrated that it was reasonable to generalise across Australia (Chapter 6). However, this generalisability would have been better guaranteed by using a sampling method that increased the percentage of participants working outside Western Australia.

Partnerships with other universities could have improved the sample.

The response rate was better in Survey 2 than Survey 1. This could have been due to consistency between the medium used for the invitation to participate and the questionnaire. Although this theory requires testing, it is likely that email communication works well with online questionnaires, and letters of invitation work well with paper questionnaires.

The final focus group was successful. However, different questions might also have been effective. Rather than asking the participants a direct form of the research questions, for example, whether the factors and competencies were clear, it might have worked well to ask the participants what they understood by each factor and competency. This could have provided evidence of common understanding, rather than participant's declared perceptions of clarity.

Explicit business items were added in the final focus group. It would have been better if these had been listed individually in the questionnaires, and consequently included in the exploratory factor analysis.

Because the senior engineers were the participants who commented on the need to add business items, it might have been useful to reverse the order in which the surveys were conducted.

The competencies were not refined based on results of Survey 1 before Survey 2 was conducted, because the approach taken allowed comparison of the results. However, as the results of the two surveys were never combined, for example for the exploratory factor analysis, it would have been feasible to refine the competency items before the second survey, based on results of the first survey.

CHAPTER 12. Recommendations for Further Research

The CEG Project has identified generic engineering competencies required by engineers graduating in Australia. The Project was designed to help develop a survey instrument to profile the competencies of graduates from an engineering program, using ratings made by workplace supervisors. This chapter begins with a suggested method for developing, validating and testing such an instrument, initially proposed in 2005 (Male and Chapman). Following this, other issues that remain to be studied are outlined.

12.1. Development, Validation and Testing of Instrument to Measure Identified Competency Factors

12.1.1. Instrument Development

It is suggested that a survey instrument could be implemented online to measure competencies of engineering graduates. The instrument would be designed to be completed independently and confidentially by (i) two engineers who have supervised the same graduate, for at least one month, not necessarily simultaneously and (ii) the graduate.

The instrument would incorporate a response format for each indicator, which allows supervisors to indicate levels of attainment of the competencies. These anchors would include descriptions of the behaviours required to demonstrate performance at each given attainment level on the scale. In determining the anchors to use, the dimensions of the behaviour that are relevant (for example, frequency, intensity, consistency) would be considered. This would increase the standardisation of ratings across supervisors and thus the reliability, and applicability of the instrument across contexts.

12.1.2. Initial Validation

Initially, the survey instrument could be tested with approximately 15 supervisors of engineering graduates and seven graduates. Multiple supervisors for one graduate would be included in order to indicate robustness of ratings across supervisors, or to estimate the average consistency of the ratings. On this basis, a reliability coefficient and a confidence interval would be generated to produce error bands. These estimates would be used in two ways. For items in which the errors are large, efforts would be made to identify the cause of this, and to further clarify or more finely operationalise the items. In cases where the band is within acceptable limits, these would be used to define the level of precision achievable in the ratings.

12.1.3. Large-Scale Validation

The final instrument would be completed by a large sample ($n > 200$) of pairs of supervisors of engineering graduates and at least as many graduates.

12.1.4. Test-Retest Data

A small group ($n = 30$) of supervisors and at least as many graduates, could be invited to complete the survey again within eight weeks of completing the initial survey. Any items that demonstrate significant variance across the two time points would be re-examined to ensure that their reference characteristics are stable traits of the individual, rather than unstable patterns of behaviour that may vary over short time periods.

12.1.5. Analysis, Final Validation and Refinement

The data collected could be analysed using traditional reliability estimates, assessments of construct and criterion related validity, and factor and item analysis. Subgroups of graduates would be formed according to (i) the graduate's engineering discipline, and

(ii) the demographic variables recorded (e.g., males vs females). Competency profiles would be developed for students from different subgroups.

The minority status of some groups of people such as women in engineering and other factors such as gender typing, could bias evaluations of the competencies of some engineering graduates (Smith *et al.* 2001, Male *et al.* 2009c).

The CEG Project finding that the importance of generic engineering competencies varies across jobs implies that reliability of ratings of competence ratings in jobs for which competency factors are less important than in other jobs should be tested.

12.2. Issues Requiring Further Research

Although important, how to help students develop the generic engineering competencies and how to formatively assess competencies, are outside the scope of the Project. It is important to identify effective learning styles, teaching methods, program structures, learning environments, and assessment methods. Issues closer to the topic of the Project, and requiring further research, are discussed below.

12.2.1. The Transition from Graduate to Established Engineer

Literature noted in the Introduction asked whether engineering grades are an indicator of success as an engineer (section 1.1.1.1). The CEG Project was designed for its results to be used to help improve engineering education. It was envisaged that the results would be used to develop an instrument for profiling the identified generic engineering competency factors of graduates by using workplace supervisors' ratings. The CEG Project Industry Advisory Committee suggested that it would be best for workplace supervisors to rate graduates one to five years after they graduate. At this stage, their competence should be evident and yet the contribution of their engineering education to their current competence should still be significant. Research to investigate

the transition from graduate to established engineer, and to senior engineer, would be helpful.

12.2.2. The Best Time and Place to Develop

Competencies

Some engineering academics believe that technical concepts require the luxury of commitment that is only possible while studying, and that competencies such as communication and teamwork can be developed easily in the workplace. This view implies that engineering education should focus on technical rather than people-related competencies.

Some students develop many generic engineering competencies before undertaking university engineering education, and there is now the possibility for workplace learning programs (Dowling 2006, Shearman and Seddon 2010).

These issues and opportunities raise research questions about the best time and place to develop various generic engineering competencies. No attempt has been made to address these in this Project.

12.2.3. Competencies for Purposes Other Than Engineering Work

12.2.3.1. Competencies Graduates Need *to Become* Engineers

The CEG Project has identified competencies required by engineers to perform their jobs well. Engineering educators have responsibilities to both their students and society, to help their students develop competencies for purposes additional to performing engineering jobs. For graduates to become engineers requires more than the competencies required to work as an engineer.

There are competencies that engineering students need in order to make the first leap from being a student to being an engineer. The shortage of engineers in Australia is due to factors other than a shortage of engineering graduates; many engineering graduates are not working as engineers (Tilli and Trevelyan in press). For an engineering program to graduate people with the technical competence to work as an engineer but insufficient inspiration, confidence, or competence to work as an engineer is to deny these people the future to which they have committed four or more years' study, and to deny society the benefits of these graduates' engineering careers. Engineering educators have a responsibility to both their students and society to avoid this tragedy.

Therefore, in addition to competencies required for engineering work and identified by the CEG Project, engineering educators should help their students to have awareness of opportunities in engineering, be inspired, be confident, and have skills required for acquiring employment and promotions. Engineering educators should also help their students to have sufficient practical competence both, to establish credibility, and to be aware of their limitations and the value of the opinions of people with more practical experience. These responsibilities demand further investigation.

12.2.3.2. Competencies for Citizenship

As discussed in section 1.7.1.4.1, engineering educators have a responsibility to help their students develop competencies to contribute to society both as engineers and as citizens. What are the competencies required for this? How can they be developed and should they be assessed? This is a separate area of research.

As raised in section 1.7.1.4.2, another question that needs to be addressed is whether engineering educators should take any responsibility for helping students to develop competencies required for the many jobs outside engineering in which engineering graduates work.

CHAPTER 13. Conclusions

The CEG Project is the first large-scale Australian study focusing on the competencies required by established engineers across all disciplines of engineering. Results support those of smaller-scale Australian studies, and large-scale studies in other countries.

The CEG Project addressed the following two main questions:

- What are the generic engineering competencies that engineers graduating in Australia require for their work as engineers?
- What are the generic engineering competency *factors* that engineers graduating in Australia require for their work as engineers?

Sixty-four generic engineering competencies (Table 17) were identified as the competencies that, along with in-depth technical competence in their field, are the generic engineering competencies that engineers graduating in Australia require for their work as engineers. The generic engineering competencies encompass knowledge, skills, attitudes, and technical and non-technical elements.

Eleven generic engineering competency factors were identified statistically among the 64 items, using exploratory factor analysis of established engineers' ratings of importance of the competencies. From this a concise, comprehensive, generic engineering competency model was developed (Chapter 7, Chapter 9). The generic engineering competency factors are Communication, Teamwork, Self-Management, Professionalism, Ingenuity, Management and Leadership, Engineering Business, Practical Engineering, Entrepreneurship, Professional Responsibilities, and Applying Technical Theory (section 9.8). The method identified a competency model with factors that are more distinct than items currently stipulated for accredited engineering education programs in Australia, either in the generic attributes (EA 2005b) or the Stage 1 Competency Standards (EA 2005a). This makes the new model more suitable

for profiling the competencies of graduates, and thereby helping to improve engineering education programs in Australia.

The first of the four sub-questions was:

Are the engineering program outcomes currently required for accreditation in Australia aligned with the identified generic engineering competencies?

The results indicate that the EA graduate attributes are well aligned with the competencies required by engineers graduating in Australia for their work as engineers (Figure 7). Therefore, the accreditation criteria are further supported by this research, and measurement of the competencies identified in this study would assist program evaluation and improvement. The eleven-factor generic engineering competency model developed in the CEG Project is more comprehensive, and more clearly structured, than the generic graduate attributes (EA 2005b) or the Stage 1 Competencies (EA 2005a) stipulated for engineering program accreditation in Australia.

Competencies were identified that could be considered as potential additions to those stipulated for accredited engineering programs. Four additional competency items identified among the 64 competencies, and not clearly included in the EA generic graduates attributes, were *cross-function familiarity*, *workplace politics*, *entrepreneurship* and *marketing*.

At a broader level, among the generic engineering competency factors, the Entrepreneurship Factor is additional to the outcomes stipulated for accreditation by ABET, EA, and the ENAEE. Similarly, only the ENAEE outcomes explicitly encompass competencies related to the Engineering Business Factor.

The second sub-question was:

Are different generic engineering competencies important for jobs with different tasks and work contexts?

Chapter 8 reported variation in the importance of generic engineering competency factors across jobs with different work contexts or tasks. This implies that diversity among the strengths of graduates is desirable and that caution will be necessary to ensure reliability of evaluations using profiles of competencies of graduates.

Finally, the third and fourth sub-questions were:

- Do engineers gender type engineering jobs?
- Specifically, are there stereotypically feminine competencies that are important to engineering jobs but affected by gender typing among engineers?

Results were consistent with under-rating of important stereotypically feminine competencies among the senior male engineers who participated in Survey 2. The implication is limited to the senior male engineers due to the method used, and whether the phenomenon would be present among other participants was not possible to test using the data collected. As discussed in Appendix XXXII, this quantitative result is consistent with others' qualitative findings, and the phenomenon could undermine stereotypically feminine competencies in engineering education.

Results of the CEG Project will help to improve engineering education in Australia. The research has implications for engineering educators, engineering education policy makers, engineering students, engineers, and prospective engineering students and their advisors (Chapter 10). Additionally the method developed, and the successful adaptation of the DeSeCo theoretical framework for conceptual understanding of competencies (OECD 2003) to generic engineering competencies, are relevant to higher education in general.

The results could be used to develop a survey instrument to profile the competencies of engineering graduates using ratings made by workplace supervisors of graduates

(section 12.1). This will help to close the loop in the continuous improvement of engineering education, and align engineering education with engineering work. More effective engineering education should help to address the engineering skills shortage in Australia. Most significantly, the results will help engineering educators to help engineering students to be successful engineers and to help society.

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APPENDICES

Appendix I. Abbreviations

<i>Abbreviation</i>	<i>Full Name</i>
ABET	Accreditation Board for Engineering and Technology
AaeE	Australasian Association for Engineering Education
APESMA	Association of Professional Engineers, Scientists and Managers, Australia
ASEE	American Society for Engineering Education
CBET	Competency-Based Education and Training
CDIO	Conceive-Design-Implement-Operate
CEG Project	Competencies of Engineering Graduates Project (this PhD project)
DeSeCo Project	Definition and Selection of Competencies Project (commissioned by the Organisation for Economic Co-operation and Development)
EA	Engineers Australia
ECUK	Engineering Council UK (now known as Engineering Council)
ENAE	European Network for Accreditation of Engineering Education
EUR-ACE	Accreditation of European Engineering Programmes
FEANI	European Federation of National Engineering Associations
IEAust	Institution of Engineers, Australia (also now known as Engineers Australia)
IEEE	Institute of Electrical and Electronic Engineers
MANOVA	Multivariate analysis of variance
MIT	Massachusetts Institute of Technology, Cambridge, Massachusetts
OECD	Organisation for Economic Co-operation and Development
QAA	Quality Assurance Agency for Higher Education (UK)
SEFI	European Society for Engineering Education
UK	United Kingdom
UK-SPEC	UK Standard for Professional Engineering Competence
USA	United States of America
UWA	The University of Western Australia
WA	Western Australia
WFEO	World Federation of Engineering Organizations

Appendix II. Full List of Competencies Before Refinement

Competencies Expected to be Required by Engineers

This list of competencies was developed from literature, conversations, a panel session (Chapter 4), and ideas. The first two surveys in the CEG Project are to determine which of these competencies and attributes are desirable in established engineers. This is a comprehensive list, which was later sorted (Appendix C) and refined to be suitable for questionnaires.

Abbreviations Noting the Nature of References

(The references are included in the main References section.)

Conf Conference paper
EJEE *European Journal of Engineering Education*
Eng Engineering (meaning that the reference is about engineering)
HE Higher Education
IJTDE *International Journal of Technology and Design Education*
JEE *Journal of Engineering Education*

The Competencies

(The bold type highlights words that indicated specific competencies.)

Awareness of Broader Context (ecological, social and economic, global, contemporary) (EA 2005b)^{Eng} (ABET 2004, p.2)^{Eng} (National Academy of Engineering 2004)^{Eng}

- keeps the big picture in mind
- identifies impact (beyond having societal or global knowledge) (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- **understands the impact of engineering solutions in a societal context** (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- **understands the impact of engineering solutions in the global context** (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- has **knowledge of contemporary issues** (ABET 2004)^{Eng}
local and global socio-economic, local to global political issues, geological and ecological issues (ABET 2004, p.2)^{Eng}
- **integrates disciplines**
- **transfers concepts** (Froyd and Ohland 2005)^{Eng JEE}

Creativity (originality/initiative, ingenuity) (Doron and Marco 1999)^{Eng EJEE} (National Academy of Engineering 2004)^{Eng} (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}

- solves problems creatively – thinking imaginatively without being restricted by conventions (Minnick and Ireland 2005)

Communication

- communicates effectively (ABET 2004, p.2)^{Eng} (National Academy of Engineering 2004)^{Eng}
- communicates effectively, not only with engineers but also with the community at large (EA 2005b)^{Eng}
- demonstrates comprehension skills – analytic ability (Doron and Marco 1999)^{Eng EJEE}
- demonstrates **written** communication skills (Doron and Marco 1999)^{Eng EJEE} (Meier *et al.* 2000)^{Eng JEE} (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)
- writes **technical documents** (an Engineering Education Australia course)
- demonstrates **oral articulacy** (Doron and Marco 1999)^{Eng EJEE} (grammar), clarity, confidence, tone, content, appropriate pace, avoidance of inappropriate jokes, adapts to audience response, awareness of audience, accent (e.g. suitability of broad Australian or aristocratic accent in the work environment) (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- demonstrates **graphical** communication of information, concepts and ideas (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- acquires and uses information **from a variety of sources**, including electronic retrieval systems (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- uses body language skills e.g. eye contact
- demonstrates **oral presentation** and communication skills (Meier *et al.* 2000)^{Eng JEE}
- demonstrates **listening** skills (Meier *et al.* 2000)^{Eng JEE}
- communicates **across disciplines** (panel session Aug 2005)
- communicates “effectively **with appropriate levels of management**” (Meier *et al.* 2000)^{Eng JEE}

- **defends and asserts one's rights**, interests, limits and needs (OECD 2002, as part of "acting autonomously")
- uses language, symbols and text interactively (OECD 2002)
- adapts tone as required
- Australian Council for Educational Research (2001, p.2)^{HE} reports on Australian project to assess graduate skills. They tested:
 - 1) written communication
 - "language and expression (including control of language conventions, clarity and effectiveness of expression
 - organization (including effectiveness and purposefulness of organization); and
 - thought (including depth of analysis of issues or information)"
- has **confidence** in own communication skills (Besterfield-Sacre *et al.* 2001)^{Eng JEE}
- creates visible competence (Minnick and Ireland 2005)
 - clearly communicating ideas
 - becoming the centre of a knowledge network (in and out of the organization)
- demonstrates communication skills across various dimensions (Hirsch *et al.* 2005)^{Eng JEE}
 - nature e.g. written, oral, mathematical, graphical, interpersonal
 - genres e.g. reports, presentations
 - tools e.g. Powerpoint
 - four concepts for communication framework: purpose, audience, tone (or style or persona), message
 - technology (or media or channel)
- demonstrates individual and organization **network competence** (Gemünden and Heydebreck 1995, Gemünden *et al.* 1996) (see notes below) e.g. maintains contacts, makes and takes opportunities to make new contacts, maintains reputation
- maintains professional manners/etiquette appropriate to the situation e.g. table manners, dress, language, appropriate greetings
- "Communications and presentations" (Maxwell-Hart and Marsh 2001)^{Eng} includes "Written communication", "Oral communication", "Telephone communication", "Management of meetings: The structure and procedures which ensure that time in meetings is planned and effective, that all the participants contribute, that the purpose is achieved and, subsequently, that the conclusions and resultant actions are reported and understood", "Business presentations", "Public meetings", "Dealing with media and VIPs: The skills with which a professional acts as a spokesperson, giving information that is factual in a courteous way, while remaining conscious of the implications of what is said and written.", "Multi-national communication: The means by which effective communication between multi-cultural people and business is professionally and mutually carried out.", "Consultations (public etc): The ability to... explain, listen and 'take-on-board' principles and specific actions or

methods that are of concern, or have an importance, to other people or parties to enhance the effectiveness of the product or service being delivered”

- “**Negotiation**: Planned discussion and bargaining that consistently allows acceptable agreement to be reached” (Maxwell-Hart and Marsh 2001)^{Eng}

Concern for People (M. Connell, Exec GM HR, Thiess, telephone conversation 2005)

- “Respect for people” (Maxwell-Hart and Marsh 2001)^{Eng} includes “Interview skills”, “Employment conditions”, “Industrial relations”, “Stress management: Recognising the consequences of pressure applied to achieve results and exercising awareness, concern and control on behalf of self and others”, “Performance appraisal”, “Training and development”, “Leadership” (expanded under leadership), “Negotiation” (expanded under communication), “Decision making”, “Job evaluation: The determination of skills required to carry out specific tasks or functions”, “**Delegation**: The act of giving responsibility and authority for a function or task to another while remaining accountable.”, “**Motivation**: Selection of the appropriate technique with which to generate enthusiasm in self and others to produce the best performance of duties”

Design

- understands the principles of **sustainable design** and development (EA 2005b)^{Eng}
- utilises a **systems approach** to design and operational performance (EA 2005b)^{Eng}
- demonstrates ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social political, ethical, health and safety, manufacturability and sustainability (ABET 2004, p.2)^{Eng}

Diversity (gender and cultural and other) (also part of ethics)

- functions effectively as an individual and in **multi-disciplinary and multi-cultural teams**
- recognises harassment and bullying when a bystander or a victim and responds in a manner which stops the behaviour
- recognises discrimination and acts to reduce it
- uses only language, jokes or behaviour which are acceptable to others
- **demonstrates cultural competencies** (Chubin *et al.* 2005)^{Eng JEE} (Gill *et al.* 2005)^{Eng Conf} (to improve diversity of gender and race within the profession, and to improve the profession’s ability to serve all people)
 - understanding of cultures and genders other than one’s own e.g. familiarity with second language/culture
 - awareness of workplace cultures shaped by dominant cultures

Emotional Intelligence (this overlaps with others, especially communication and self-management)

- is aware of others' perceptions
- is aware of others' motivation
- is aware of personal impression given to others (i.e. how one is perceived by others)
- exercises personal courage
- has a thick skin
- achieves positive outcomes from criticism / mistakes (this is elsewhere)
- responds appropriately to failure or mistakes
- **learns from experience** (this is elsewhere)
- Australian Council for Educational Research (2001)^{HE} reports on Australian project to assess graduate skills. They tested:
 - 2) Interpersonal understandings**
 - "Insight into the feeling, motivation and behaviour of other people
 - recognize how that insight may be applied in order to effectively help or work with others, including effective feedback, listening, communication, negotiation, teamwork and leadership"

Entrepreneurship / Innovation (Crebert *et al.* 2004)^{HE}

Note: In the relevant literature, "innovation" does not refer to initiative. It refers to ability to take initiative and make it profitable, which is similar to entrepreneurship.

Bodde (2004) wrote a book which refers to two technological companies: EnerTech Environmental and Nth Power Technologies.

"It would appear that the chief qualification to becoming a technological entrepreneur is a burning desire to become a technology entrepreneur"(p.19).

"The ability to develop an effective founding team is one of the central skills of the successful entrepreneur" (p.20). This needs

- a lead entrepreneur understanding his or her own limitations, and capacity and limitations of other team members
- experience and relevant industry connections
- team cohesions
- shared commitment and mutual respect.

Bodde recommends that an entrepreneur:

- practises "coachability" i.e. **capacity to respond to sound advice** (p.109)
- practises **honesty**, meaning e.g. honest to directors etc. about bad news (p.109)

- uses market insight, technology insight and entrepreneurial innovation (Ch.2) “The most discerning entrepreneurs listen to and understand the market context” (p.57).
- manages intellectual capital: developing, protecting and sharing it when advantageous (p.140)
- **tolerates risk and insecurity** (Bodde gives an example of an engineer who left a venture due to these factors)
- “**maintains a sense of urgency** as a matter of personal habit” (p.195, Ch. 11 Toward a Personal Entrepreneurial Strategy)
- **learns continuously** by listening to the markets and technology and knowing when to change tack (pp. 196-197, Ch.11)

A technical venture needs a complete management team including technical, marketing and sales skills (p.198). There must be **trust and respect within the team** (p.198).

(Bodde 2004) is reviewed in *JEE* 94, 4, Oct 2005. The review cites websites helpful for engineering educators hoping to include entrepreneurship in their curricula:

- entrepreneurship in engineering education (ASEE Entrepreneurship Division)
- entrepreneurship at all levels of education (Ewing Marion Kauffman Foundation)
- entrepreneurship in university education with a program specifically to facilitate entrepreneurship in engineering education programs (National Collegiate Inventors and Innovators Alliance (NCIIA))
- An entrepreneurship program in engineering at Stanford and offered across the university, including undergraduate and graduate education and research projects. The program also holds conferences around the world every year and has a site with resources such as syllabi and suggested texts, to help anyone setting up units in entrepreneurship (Stanford Technology Ventures Program (STVP)).

Ethics

- **Practise engineering in accordance with the code of ethics**
- **understands professional and ethical responsibilities and commitment to them** (EA 2005b)^{Eng}
- maintains “high ethical standards and a strong sense of professionalism... recognizing the broader contexts” (National Academy of Engineering 2004)^{Eng}
- practises ethical decision-making and behaviour (Meier *et al.* 2000)^{Eng JEE}
- understands the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development (EA 2005b)^{Eng}
- understands professional and ethical responsibility (ABET 2004, p.2)^{Eng Eng}
- uses **moral reasoning skills** (Kreiner and Putcha 2005)^{Eng Conf}

- makes “informed ethical choices” (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)
- evaluates “the ethical dimensions of professional engineering and scientific practice” (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)
- “Demonstrates knowledge of a professional code of ethics” (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)
- works within the professional codes for a licensed engineering institution (Engineering Council UK 2003, p.5)
 - “Guidelines for Institution Codes of Conduct. Each licensed engineering institution will place a personal obligation on its members to act with integrity, in the public interest, and to exercise all reasonable professional skill and care” (p.13).
 - prevent avoidable danger to health or safety
 - prevent avoidable adverse impact on the environment
 - maintain their competence
 - undertake only professional tasks for which they are competent
 - disclose relevant limitations of competence
 - accept appropriate responsibility for work carried out under their supervision
 - treat all persons fairly, without bias and with respect.
 - encourage others to advance their learning and competence.
 - avoid where possible real or perceived conflict of interest.
 - advise affected parties when such conflicts arise.
 - observe the proper duties of confidentiality owed to appropriate parties.
 - reject bribery.
 - assess relevant risks and liability, and if appropriate hold professional indemnity insurance
 - notify the institution if convicted of a criminal offence or upon becoming bankrupt or disqualified as a Company Director
 - notify the institution of any significant violation of the Institution’s Code of Conduct by another member (pp. 7-11 separately list competencies for Chartered and Incorporated Engineers).
- “Demonstrates ethical practice.” (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)

The following are taught as ethics to engineering students: professionalism, responsibility, maintenance of necessary confidentiality, recognition and avoidance of conflict of interest, risk and safety, relationships between engineers and managers, loyalty, whistle-blowing (Loui 2005)^{Eng JEE}.

Leadership (EA 2005b)^{Eng} (Meier *et al.* 2000)^{Eng JEE} (National Academy of Engineering 2004)^{Eng}

- “Leadership: The initiative, vision and confidence that encourage others to carry out tasks properly under direction” (Maxwell-Hart and Marsh 2001)^{Eng}

Lifelong Learning expectation of the need to undertake lifelong learning, and a capacity to do so (ABET 2004, p.2)^{Eng} (EA 2005b)^{Eng} (Meier *et al.* 2000)^{Eng JEE} (National Academy of Engineering 2004)^{Eng}

Items below are listed in the Engineering Education Assessment Methodologies and Curricula Innovation Attributes (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000)^{Eng}

- learns new techniques/to use new resources/equipment quickly
- learns independently
- has a firm grasp of fundamental mathematics and science concepts
- demonstrates reading, writing, listening and speaking skills
- demonstrates an awareness of what needs to be learned
- follows a learning plan
- identifies, retrieves and organizes information
- understands and remembers new information
- demonstrates critical thinking skills
- demonstrates ability to reflect on own understanding

lifelong learning (Mourtos 2003, pp. 15-16)^{Eng Conf}

- accesses “information effectively and efficiently from a variety of sources”
- reads critically and assesses “the quality of information available”
- categorizes and classifies information
- “analyze new content by breaking it down, asking key questions, comparing and contrasting, recognizing patterns and interpreting info”
- “synthesizing new concepts by making connections, transferring prior knowledge and generalizing”
- “model by estimating, simplifying, making assumptions and approximations”
- “visualizing (e.g. creating pictures in their mind that help them ‘see’ what the words in a book describe)”
- “reasoning by predicting, inferring, using inductions, questioning assumptions, using lateral thinking and inquiring”

Management (EA 2005b)^{Eng}

- manages others (part of an Engineering Education Australia course)
- manages projects (Maxwell-Hart and Marsh 2001, Burt 2004)
- manages contracts (Maxwell-Hart and Marsh 2001) (offered by Engineering Education Australia)
- manages finances (offered by Engineering Education Australia)
- manages maintenance (offered by Engineering Education Australia)

- manages risk (offered by Engineering Education Australia)
- manages commissioning (part of a course offered by Engineering Education Australia)
- understands “contemporary business concepts” (Meier *et al.* 2000)
 - overall big picture of the organization
 - organizational vision, strategies and performance outcomes
 - how one function integrates with other functions to achieve performance goals
 - strategic thinking, analysis and planning
 - time as basis for competition (consistent with Bodde)
 - change in the competitive environment and how it affects a firm’s operation (consistent with Bodde)
 - performing accurate cost/benefit analysis
 - analyzing alternatives based on cost vs. benefits
- understands “customer focused quality” (Meier *et al.* 2000, p.381)
 - “customer expectations and satisfactions
 - customer orientation and focus
 - recognizing internal and external customers
 - implementing the tools and components of quality
 - cost of quality and quality failure
 - recognizing and valuing the quality of a firm’s products”
- **manages organizational competencies**
- manages intellectual property
- **manages commercialisation / innovation**
- manages change in the work environment (Meier *et al.* 2000)
- has mastery of “the principles of business and management” (National Academy of Engineering 2004)
- “**Corporate management**” (Maxwell-Hart and Marsh 2001) includes “Corporate strategy”, “Business plans and objectives”, “Organisation and management structure”, “Role of officers”, “Specialist functions and their management”, “Memorandum and articles” (legal), “Mergers and acquisitions”, “Financial arrangements”, “Bond and warranty facilities”, “Political and external influences”, “Stock market and City”, “Values and culture”. (This is too specific for the surveys in the CEG Project.)
- business strategy “**Business management**” (Maxwell-Hart and Marsh 2001) includes “Business analysis (SWOTs)”, “Key selling points (KSPs)”, “Key performance indicators (KPIs)”, “Benchmarking”, “Innovation”, “Value management and engineering: The process and systems to measure and deliver innovation”, “Achieving best value: On-going liaison with clients to ensure that the product or service being delivered meets or exceeds their overall needs and requirements”, “Supply chain management”, “Formation of joint

ventures/alliances”, “Role and management of winning work” (appears to be tender preparation including estimating), “**Development and management of teamworking**” (definition included below under teamwork), “**Interdisciplinary skills management**: The understanding of the complex interfaces between different outlook and working practices while harnessing key skills to advance the cause of delivering the overall product or service”, “**Change management**”, “Risk management: Ability and procedures to identify potential risks in any context and operate a system that defines, shares and allocates their management to the party that is best able to deal with them.”, “Knowledge management”, “Stakeholder relationships: The bringing together of the parties that depend on the success of a product or service and working together to match desires, wants and mutual benefits”, “Training and development policy”, “Operating ethics: The definition, understanding and implementation of an appropriate ‘code’ by which an organisation responsibly conducts and develops its business.”

- “Financial and management systems” (Maxwell-Hart and Marsh 2001)
“Reporting systems”, “Establishing a budget”, “Cost control systems”, “Cash flow”, “profit and loss account”, “Balance sheet A statement produced at a given time showing the assets and liabilities of the business”, “VAT and taxation”, “Project and private finance: The methods by which clients are able to pay for the work they commission and the effects these have on the release of cash in payment for services, goods or work completed”, “Whole life costing”, “EU and government grants”
- “The client and relationships” (Maxwell-Hart and Marsh 2001) includes “Client focus: Development of relationships with clients to ensure that their key business objectives, ‘drivers’ and needs are properly identified and understood”, “Delivery to meet clients’ needs”, “Client satisfaction and measurement”, “**Predictability of time and cost**”, “Partnering/alliancing”, “Team integration” i.e. integration of disciplines in a team
- manages organizational networking and link to business strategy (Gemünden and Heydebreck 1995)

Marketing

- “Promotion and business development” (Maxwell-Hart and Marsh 2001)
“Marketing strategy and planning”, “Market research”, “Promotional techniques”, “Proposal and presentations: The written, verbal or electronic techniques used to secure a business opportunity by invitation or as a consequence of targeted marketing activities”, “Public relations”, “Assessing key selling points (KSPs)”, “Identification of a key client base”, “Identification of clients’ needs” (This was also noted in panel session August 2005), “Business relationship development”, “Key account management: The systems and procedures between a client and supplier to focus the delivery of services that better match the client’s needs and requirements.

Occupational Health and Safety (OHS)

- legislation, regulations, procedures, management systems, safety training, policies, manuals, quality implementation, environment policy and procedures, sustainability,

environment management systems, accreditation and auditing procedures (Maxwell-Hart and Marsh 2001)

- respects OHS
- respects feelings of others, does not say or do things which hurt others unnecessarily, does not blame carelessly, acknowledges difficulties, acknowledges effort and achievements

Personal Attributes

- respects other people's time
- respects other people's space
- takes responsibility for errors (i.e. does not blame others)
- is honest, trustworthy, fair (Loui 2005) ^{Eng JEE}
- is conscientious, diligent, persistent (Loui 2005) ^{Eng JEE}
- has **confidence** (Loui 2005) ^{Eng JEE}
- practises "**loyalty and commitment to the organization**" (Meier *et al.* 2000, p.381) ^{Eng JEE}
- maintains an "**overall positive outlook** toward job and coworkers" (Meier *et al.* 2000, p.381) ^{Eng JEE}
- "Taking pride of ownership in their work" (Meier *et al.* 2000, p.381) ^{Eng JEE}
- "Applying best practices for their particular job" (Meier *et al.* 2000, p.381) ^{Eng JEE}
- "Committed to doing their best" (Meier *et al.* 2000, p.381) ^{Eng JEE}
- "**dynamism, agility, resilience, and flexibility**" (National Academy of Engineering 2004, p.56) (Meier *et al.* 2000) ^{Eng JEE}
- Reliability "Appreciating punctuality, timeliness and deadlines" (Meier *et al.* 2000, p.382) ^{Eng JEE}

Personality Dimensions which may be relevant and for which instruments exist:

- Interpersonal Style Index (ISI)
- NEO Personality Inventory (the "big five": neuroticism, extraversion, openness to new experiences, conscientiousness, agreeableness)
- learning styles

Self Regulation

- functions effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member (EA 2005b)^{Eng}
- manages personal time
 - prioritises demands
 - estimates time to complete tasks
 - keeps to deadlines
- “Planning work to complete projects on time.” (Meier *et al.* 2000)^{Eng JEE}
- motivates self
- is motivated (French *et al.* 2005)^{Eng JEE}
- focus (panel session August 2005)
- manages self (part of Engineering Education Australia course) – time, emotions, focus, education, physical health
- forms and conducts life plans and personal projects (OECD 2002, as part of "acting autonomously")
- takes responsibility (OECD 2002, as part of "acting autonomously")
- has a career plan and strategy (Crebert *et al.* 2004)^{HE}
- continuously manages the improvement of resume (Minnick and Ireland 2005)
- deals with change in the work environment (Meier *et al.* 2000)^{Eng JEE} (“Deals” could be positive or negative. “Works well” would be preferable.)
- controls temper

Sustainability Knowledge and Attitude

- has understanding of the principles of sustainable design and development (EA 2005b)^{Eng}

For sustainability, engineers will need to understand (Beder 1996)^{Eng}

- “What sustainability is and the philosophical concepts that are associated with it, for example intergenerational equity and the precautionary principle
- why sustainability matters and the consequences of not achieving it
- the social context of engineering activities and the factors working against the introduction of sustainable technologies
- the engineer's role and responsibilities in advising policy makers and promoting sustainability.”

Teamwork (Doron and Marco 1999)^{Eng EJE} (Meier *et al.* 2000)^{Eng JEE}

- functions effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member (EA 2005b)^{Eng}
- “Team integration: The practical application to utilize and focus a project’s interdisciplinary team to allow all parties to effectively input their expertise to meet the specific goals and objectives.” (Maxwell-Hart and Marsh 2001)^{Eng}
- “Partnering/alliancing: The implementation of teamworking ethics to involve all appropriate parties and expertise related to a specific project or series of projects to ensure that the best whole-life value is delivered to meet the client’s needs.” (Maxwell-Hart and Marsh 2001)^{Eng}
- responds with visible urgency when required
- an ability to function on multi-disciplinary teams (ABET 2004, p.2, includes levels of achievement)^{Eng}
 - Outcome elements identified are:
 - Collaboration/Conflict Management
 - Team Development
 - Interpersonal Style
 - Conflict Management
 - Participation
 - Team Communication
 - Active Listening
 - Feedback (giving and receiving)
 - Influencing others
 - Sharing information
 - Team Decision-making
 - Defining a problem
 - Innovation and idea generation
 - Judgement / Using facts
 - Reaching Consensus
 - Self-Management
 - Managing meetings
 - Personal conduct
- understands how “one’s job activities impact overall performance” (Meier *et al.* 2000)^{Eng JEE}
- places “welfare of the group over self” (Meier *et al.* 2000)^{Eng JEE}
- is “flexible in dealing with others” (Meier *et al.* 2000)^{Eng JEE}
- “Being a good coach or mentor for co-workers” (Meier *et al.* 2000)^{Eng JEE}
- “Development and management of teamworking: The bringing together of all relevant parties and/or disciplines and ensuring maximum working efficiency, contribution and performance by developing common goals, objectives and mutual benefits.” (Maxwell-Hart and Marsh 2001)^{Eng}

- Ohland *et al.*'s (2005)^{Eng Conf} teamwork peer assessment instrument (M. Ohland, email, 22 January 2006) includes the following (Each dimension has behavioural anchors from negative to positive (personal communication, negative behaviours are not included below):
 - contributes to the team's work – does timely work of high quality, even help other teammates to complete their work when they are having difficulty
 - interacts well with teammates – “asks for and shows interest in teammates ideas and contributions”, listens, “respects and responds to feedback from teammates”
 - keeps the team on track – monitors team progress, notices problems and factors that help, alerts the team to threats to progress “and suggests solutions”, “gives teammates specific timely and constructive feedback”
 - expects quality – expects and seeks excellent performance from the team
 - has relevant knowledge, skills and abilities – “demonstrates knowledge, skills and ability to do excellent work”. (Instrument also includes knowledge, skills, attitudes to perform the role of any team member. This is a curious idea because it contradicts the idea of complementary team members. Perhaps Ohland's method selected this item because his model was developed for teams of students.)

Technical

- has “in-depth technical competence in at least one engineering discipline” (EA 2005b, p.5)^{Eng}
- has technical skills (Doron and Marco 1999)^{Eng EJEE}
- works with precision (Doron and Marco 1999)^{Eng EJEE}
- uses sound knowledge and understanding of mathematics, science and technical engineering principles (EA 2005b)^{Eng} (ABET 2004, p.2)^{Eng} (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- has ability to apply the above and transfer across disciplines
- “has ability to design and conduct experiments as well as to analyze and interpret data” (ABET 2004, p.2)^{Eng} (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
- “has ability to design a system, component or process to meet desired needs within realistic constraints such as economic, environmental, social political, ethical, health and safety, manufacturability and sustainability” (ABET 2004, p.2)^{Eng} (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}
 - Levels of achievement of this are in the Engineering Education Assessment Methodologies and Curricula Innovation Attributes (Engineering Education Assessment and Methodologies and Curricula Innovation Project 2000, includes levels of achievement)^{Eng}. 14 “elements” are identified: “Need Recognition”, “Problem Definition”, “Planning”, “Management”, “Information Gathering”, “Idea Generation”, “Modeling”, “Feasibility”, “Evaluation”,

“Selection/Decision”, “Implementation”, “Communication”, “Documentation”, “Iteration”

- has ability to use the techniques, skills and modern engineering tools necessary for engineering practice" (ABET 2004, p.2)^{Eng}
- keeps up to date with “technology trends and their applications” (Meier *et al.* 2000, p.381)^{Eng JEE}
- “Utilizing information systems” (Meier *et al.* 2000, p.381)^{Eng JEE}
- has confidence in understanding of scientific principles (note on Besterfield-Sacre’s work below)
- has “strong analytical skills” (National Academy of Engineering 2004, p.54)^{Eng}

Thinking

- “Handling multiple responsibilities simultaneously” (Meier *et al.* 2000, p.382)^{Eng JEE}
- “Complex problem identification and problem solving skills” (Meier *et al.* 2000, p.382)^{Eng JEE}
- has “day-to-day trouble-shooting skills” (Meier *et al.* 2000, p.382)^{Eng JEE}
- has “ability to utilise a systems approach to design and operational performance” (EA 2005b, p.7)^{Eng}
- “Process and systems thinking” (Meier *et al.* 2000, p.381)^{Eng JEE}
- has design process knowledge (Christiaans and Venselaar 2005)^{Eng IJTDE}
- has design skills
- practises reflection (Olds 2000, Christiaans and Venselaar 2005)^{Eng IJTDE}.
- practises reflexion (Lee and Taylor 1996b)^{Eng} (“reflexion” refers to “self-reflection”, as for a reflexive verb)
- thinks quickly
- transfers knowledge between contexts
- integrates engineering with other professional input
- acts within the big picture / the larger context (OECD 2002, part of "acting autonomously") (This is a thinking style as well as knowledge.)
- uses spatial visualization (Humphreys *et al.* 1993) These authors note the relationship between a composite of spatial visualization and mechanical reasoning and group membership for engineers and physical scientists. Boersma *et al.*

(2004)^{Eng Conf} report improved retention gained by an initiative to improve undergraduates' spatial visualization skills.

- makes decisions (Crebert *et al.* 2004)^{HE} within necessary time and information constraints (Air Vice Marshal J. Hammer, "Leadership: Making a Difference, breakfast speech for WA Division, Engineers Australia, 2004)
- "Decision making: Judgement exercised with responsibility once all relevant factors have been taken into account" (Maxwell-Hart and Marsh 2001)^{Eng}
- "Innovation and creativity in problem solving" (Meier *et al.* 2000, p.382)^{Eng JEE} (This is a different use of innovation from that intended elsewhere in this list.)
- has knowledge of theories on thinking strategies
- uses metacognitive skills
- pays attention to detail when necessary
- applies perfectionism when necessary
- Problem-solving skills
 - an ability to identify, formulate and solve engineering problems (ABET 2004, p.2)^{Eng}
 - Levels of achievement of this are in the Engineering Education Assessment Methodologies and Curricula Innovation Attributes (2000). Elements identified are:
 - Identifying problem and opportunities
 - Constructing a problem statement and system definition
 - Formulating problem and abstraction
 - Collecting data, resources and information
 - Modelling the problem: translation
 - Validating
 - Designing experiments (see ABET outcome b)
 - Solving or experimenting
 - Interpreting results
 - Implementing and documenting
 - Using feedback and improving
 - ability to undertake problem identification, formulation and solution (EA 2005b, p.7)^{Eng}
- has confidence in own basic engineering knowledge and skills (note on Besterfield-Sacre below)
- has confidence in decisions
- has "**dynamism, agility**, resilience, and **flexibility**" (National Academy of Engineering 2004, p.56)^{Eng}
- Australian Council for Educational Research (2001)^{HE} reports on Australian project to assess graduate skills. They tested:

3) Critical Thinking

- “*Comprehension* in order to identify explicit and implicit meaning
- *Analysis and Influence* in order to identify definitions being applied, claims being made, points of view, key issues, lines of reasoning, evidence, conclusions, arguments, assumptions, logical flaws, logical implications, missing information, rhetorical devices, ambiguity, analogies etc; and
- *Synthesis and Evaluation* in order to judge aspects such as the credibility and validity of evidence, lines of reasoning, conclusions and arguments.” (p.2)

4) “Problem-Solving

- Analysis, interpretation and evaluation of information for problem identification and decision making;
- Translation and reorganization of information in progressing toward problem solution (including logical categorization of information for task planning, translation and reorganization of information to solve a problem); and
- Application of basic quantitative reasoning and numeracy to solve a problem
- Where the following process may be applied:
 - Identify, comprehend, restate the problem
 - Identify and analyze information relevant to the problem
 - Represent features of the problem
 - Translate, reorganize, synthesize and apply information relevant to a problem
 - Conceptualize/generate strategy
 - Evaluate solution strategies and their outcomes” (p.3)

Tools (OECD 2002, as part of "tools")

- ability to use tools interactively e.g. ICT, software tools, mechanical tools
- ability to use mathematical tools interactively
- “ability to apply knowledge of basic science and engineering fundamentals” (EA 2005b, p.3)^{Eng}
- “ability to use the techniques, skills and modern engineering tools necessary for engineering practice” (ABET 2004, p.2)^{Eng}

Workplace / Career Savvy

- action orientation (Bodde 2004)
- shares information with recognition of the currency of people's information i.e. you get as much as you contribute (Trevelyan 2006, role E23)
- in contrast to the above (Meier *et al.* 2000)^{Eng JEE} list “sharing information and cooperating with co-workers” as a competency
- “dealing with the politics of the workplace” (Meier *et al.* 2000)^{Eng JEE}
- Gill, Mills, Sharp, & Franzway (2005)^{Eng Conf} recommend all graduates to be aware of “social and political dimensions of the typical engineering workplace” “a world constrained by gendered world views and practices” introduction to

“formal and informal aspects of workplace culture” would provide strategies avoiding stereotypical roles

- awareness of workplace culture – ability to recognise the workplace culture and the ways to survive thrive and achieve

Notes

Personality characteristics must be included only with great care. Issues related to personality variables and employment (particularly personnel selection) are noted by Arthur, Woehr and Graziano (2001). There can be “bias associated with social desirability”. There may be legal implications.

Crebert *et al.* (2004)^{HE} discuss workplace experience helping students “...evaluate and develop work-related personal attributes (including diplomacy, cooperation, workplace etiquette and leadership, develop specific communicative and interactive abilities, establish career plans and strategies. Same paper talks about how undergraduate education can better develop “..., awareness of context, capacity to move between different viewpoints, languages and systems of knowledge, self-regulation and critical self-reflection. (The paper refers to another paper for this.) The paper also cites another reference which talks about environments which allow transfer of generic skills. One is “capacity to learn from experience”. Another is “life-long learning skills and **dispositions**”. The paper by Crebert *et al.* is about which generic competencies can be learnt at university, during work experience etc. Those best developed in the workplace are: leadership and entrepreneurial skills, assuming responsibility and making decisions, and demonstrating high ethical standards.

Loui (2005) found that students consider these and the following as important for professional engineers: honesty, trustworthiness, fairness, conscientiousness, diligence, persistence, confidence and a sense of personal worth.

Organization network competence (i.e. relationships with other organizations) and technological competence as needed by manufacturing businesses were studied by (Gemünden and Heydebreck 1995). They identified different classifications for manufacturing businesses by business strategy. Basically, a company can place strategic priority on: the organization being a “technological leader”, or “customer-focused developer”, a “cost leader”, a “specialiser”, or a “dissipater” (i.e. not prioritising anything). These different business strategies, and the industry type and the size of the business, determine the technological network maintained (e.g. R&D cooperation with other companies, contacts with research institutes or universities, exchange of technical know-how with customers).

In the same area of work as Gemünden *et al.*, and cited by them, is a paper which quantitatively assesses the link between communication with customers in development of new products and the success of the new product. It looks at the stages of the process when interaction is helpful and which customers are best to interact with Grunder and Homburg (2000).

Related work classifies organizations according to the intensity of technological collaboration with external organizations and also the patterns of this communication i.e. whether it is with suppliers, customers, universities etc. (Gemünden *et al.* 1996).

The paper makes no strict conclusions but makes some about the network required for product innovation and different conclusions for process innovation. It has similarities with Survey 1, except that Survey 1 considered individuals instead of organizations. They asked subject matter experts for this reason. Survey 1 participants were job incumbents.

Meier *et al.*'s (2000) work is particularly relevant because its purpose was similar to the CEG Project. It determined what is important for science, mathematics, engineering and technology employees and where there are gaps in curricula. All but the five least important items were included in this list of competencies.

Besterfield-Sacre *et al.* (1998) considered assessment of students' attitudes and self-assessments. These were noted, but not considered relevant to this list of competencies. They are summarised below (full sentence definitions are provided in the paper).

General impressions of engineering, perception of the work engineers do and the profession of engineering,... engineering perceived as being an "exact" science, engineering comparing positively to other fields of study,... confidence in chemistry [This was for industrial engineers.], confidence in communication skills, confidence in basic engineering knowledge and skills, confidence in engineering skills (creative thinking, problem solving and design skills) (p.138)

A review of higher education in the UK reported,

Recommendation 21

We recommend that institutions of higher education begin immediately to develop, for each programme they offer, a "programme specification" which identifies potential stopping-off points and gives the intended outcomes of the programme in terms of:

- the knowledge and understanding that a student will be expected to have upon completion;
- key skills: communication, numeracy, the use of information technology and learning how to learn;
- cognitive skills, such as an understanding of methodologies or ability in critical analysis;
- subject specific skills, such as laboratory skills
(Dearing 1997)^{HE}.

Organizational commitment is discussed in the literature. It was not included in this list because its components are present.

Appendix III. Sorted Competencies

This is the result of the first stage of distilling the competencies. They were grouped into categories used by Birkett (1993).

COGNITIVE SKILLS

Technical Skills

- Understands fundamental principles of mathematics, science and technical engineering
- Has confidence in understanding of mathematics, science and technical engineering principles
- Has expert competence in an area of technical specialty
- Uses techniques, modern engineering tools necessary for engineering practice
- Acquires and uses information from a variety of sources
- Uses analytical skills
- Keeps up to date with trends and their applications
- Uses correct English grammar
- Uses IS and IT systems
- Day-to-day trouble shooting skills
- Attends to detail when required
- Visualizes three dimensional objects
- Thinks quickly (This is part of mental agility along with creativity, thirst for change, calculated risk-taking and action orientation.)
- Works quickly

Analytic/Constructive Skills

- Undertakes lifelong learning
 - Follows a learning plan
 - Learns independently
 - Identifies, retrieves and organizes information
 - Understands and remembers new information
 - Thinks critically and assesses quality of information
 - Reflects on own understanding
 - Synthesises new concepts by making connections, transferring knowledge and generalising
 - Models by estimating, simplifying, making assumptions and approximations
 - Visualizes
 - Reasons by predicting, inferring, using inductions, questioning assumptions, using lateral thinking and inquiring
- Thinks critically
- Knows about contemporary socio-economic, political, geological and ecological issues both local and global
- Has ability to design and conduct experiments
- Analyses and interprets data
- Integrates disciplines
- Transfers concepts across disciplines and contexts
- Comprehends technical and other documents– analytic ability

- Writes technical and other documents
- Graphically communicates information, concepts and ideas
- Uses a systems approach to design and operational performance within realistic constraints such as economic, environmental, social political, ethical, health and safety, manufacturability, maintainability and sustainability
 - Include problem definition, modelling, evaluation etc
- Innovates / demonstrates entrepreneurial skills
 - Maintains market insight
 - Operates with sense of urgency
 - Uses technological insight
- Uses simulation techniques
- Identifies, formulates and solves problems
 - Identifies problems and opportunities
 - Defines the problems
 - Collects data, resources, information
 - Models the problem
 - Validates
 - Designs experiments
 - Interprets results
 - Implements and documents
 - Uses feedback and iterates

Appreciative Skills

- Evaluates the ethical dimensions of engineering practice
- Demonstrates awareness of the broader context
- Identifies impact on economy, environment and society at all levels from local to global
- Solves problems creatively – thinking imaginatively without being restricted by conventions
- Makes decisions within necessary time and information constraints

BEHAVIOURAL SKILLS

Personal Skills

- Learns from experience including mistakes
- Responds to sound advice
- Maintains honesty
- Maintains trustworthiness
- Works conscientiously / committed to doing own best
- Knows personal strengths and weaknesses
- Reflects on own performance
- Manages own professional development / lifelong learning
- Manages own life plan and career plan and strategy
- Has confidence to take calculated risks
- Has confidence in own ability
- Perseveres
- Maintains resilience
- Manages emotions
- Motivates self

- Maintains focus
- Is responsible
- Tolerates risk and insecurity
- Is dynamic
- Demonstrates flexibility/adaptability
- Demonstrates reliability with respect to punctuality, timeliness, deadlines
- Manages personal time
 - Prioritises demands
 - Estimates time to complete tasks
 - Keeps to deadlines
- Manages physical health
- Works well with change in work environment
- Works with precision
- Handles multiple responsibilities simultaneously
- Action orientation – commitment to making things happen and keeping things lively
- Thirst for change – valuing departures from established patterns of doing things
- Personal visibility – creating visible competence
 - Clearly communicating your ideas
 - Becoming the centre of a knowledge network (in and out of the organization)

Interpersonal Skills

- Demonstrates overall positive outlook towards job and co-workers
- Has confidence in own communication skills
- Communicates with engineers, across disciplines, with all levels of workers and management and the community at large (four dimensions)
- Demonstrates oral articulacy
- Adapts tone
- Uses appropriate body language
- Has ability to be assertive
- Defends and asserts one's rights, interests, limits and needs
- Uses insight into the feelings, motivation and behaviour of others to help or work with others (providing feedback, listening, communicating, negotiating, working in teams and leading)
- Provides constructive feedback
- Listens to and understands different viewpoints
- Helps others to learn in the workplace
- Has awareness of others' perception of self
- Is not easily damaged by others (thick skin)
- Learns from feedback
- Has ability to portray confidence
- Has ability to portray humility
- Has ability to portray empathy
- Listens reflectively
- Portrays urgency when required
- Reads and adapts to audience response
- Makes presentations e.g. to clients
- Chairs meetings
- Participates constructively in meetings
- Maintains visibility
- Facilitates forums/public meetings

- Communicates one-to-one, by telephone, in letters and by email (four dimensions)
- Recognises and operates within workplace etiquette
 - Dresses appropriately for the occasion (time and place) and company
 - Remains courteous / uses appropriate manners
 - Uses appropriate table manners
 - Avoids coarse language
 - Respects others' time
 - Respects others' space
- Demonstrates diplomacy
- Demonstrates cultural competence
- Communicates with people in other countries
- Understands how dominant cultures shape workplaces
- Demonstrates respect for people from all backgrounds, levels of education and gender
 - Does not harass or discriminate
 - Does not tolerate harassment or discrimination
- Negotiates
- Demonstrates concern for others
- Delegates when required
- Motivates others
- Leads others
- Participates in teams including multicultural, multidisciplinary and mixed gender teams
 - Manages conflict
 - Communicates appropriately (e.g. encouraging others to participate, balancing speaking and listening)
 - Assists team decision-making
 - Recognises capacity and limitations of other team members
 - Trusts team members
 - Maintains team cohesions
 - Contributes to the team's work
 - Keeps the team on track
 - Facilitates teams – being a team member who also
 - Monitors the team development and
 - Facilitative empowerment – empowering the team members to work together by treating all as equals, respecting, listening to others and cooperating
- Develops and manages teams
- Manages others
- Supervises others
- Trains/coaches others
- Mentors others
- Spans boundaries
 - Links people across the organization informally
 - Has a broad based knowledge of the workings of the organization (i.e. not restricted to own section)
 - Continuous learners – listening across different parts of the organization

Organizational Skills

- Maintains high ethical standards and professional responsibilities

- Communicates with media
- Maintains confidentiality
- Maintains loyalty and commitment to employer
- Understands structure of the organization
- Understands the social and political dimensions of the workplace e.g. understanding “a world constrained by gendered world views and practices” and “formal and informal aspects of workplace culture” would provide strategies avoiding stereotypical roles
- Integrates teams
- Develops and maintains a network of colleagues, clients etc
 - Makes and takes opportunities to make new contacts
 - Actively maintains relationships
 - Maintains reputation
- Develops and maintains networks between organizations
- Manages projects
- Manages a function either for a specific job or overseeing the function over multiple jobs e.g. estimation, tender submissions, cost control, tender submissions, contracts
 - Manages estimating and tender submission
 - Manages contracts
 - Manages finances and management systems e.g. reporting systems, budgeting, cost control systems, cash flow, profit and loss account, financing, balance sheet, goods and services tax, whole-life costing
 - Manages maintenance
 - Manages operational performance
 - Manages occupational health and safety
 - Manages risk and contingencies
 - Manages commissioning (this would be “finalising the project” under “project management”)
 - Manages change in the work environment
 - Manages quality
 - Manages organizational or project competencies and training and development
 - Manages IP
 - Knowledge management
 - Management of client and stakeholder relationships
 - Manages commercialisation/innovation
- Manages the business including e.g. organizational vision, strategies and performance outcomes, integration of functions, strategic thinking, analysis and planning, change in the competitive environment, cost/benefit analyses, key selling points, key performance indicators, liaison with clients, supply chain management, formation of ventures, alliances
- Corporate management including business plans and objectives, mergers and acquisitions, financial arrangements, values and culture, political and external influences, stock market etc
- Marketing

Appendix IV. Invitation to Panel Session

Office of the Dean (M017)

Faculty of Engineering, Computing and Mathematics
The University of Western Australia
35 Stirling Highway, Crawley, WA 6009
Phone: +61 8 6488 3704
Fax: +61 8 6488 1026
CRICOS No: 00126G
Email: dean@ecm.uwa.edu.au
Professor Mark B Bush

22 July 2005

<Title> <Name>
<Position>
<Organization>
<Postal Address>

Dear <First Name>,

The Faculty of Engineering, Computing and Mathematics is undertaking a project to develop methods for surveying employers to produce a profile of our graduates. A fundamental component of the project involves identifying the key competencies required of engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. The study is being conducted as a Ph.D. project by Ms. Sally Male, under the supervision of Dr. Elaine Chapman of the Graduate School of Education and me.

A number of panel sessions will be held with representatives both from the university and from industry to help identify the key competencies. I would like to invite you or a nominee to participate in a forthcoming session that will focus on the roles of engineers working in research-oriented environments.

Details of the panel session to which you are invited:

Time: 5:30pm
Date: Thursday, 11 August
Venue: Billings Room, Third Floor,
Electrical and Electronic Engineering Building
The University of Western Australia.

Light refreshments will be provided at the session. An information sheet providing further details is attached.

The participation of industry representatives will be essential to the success of this project. We will be most grateful if you can spare some time to join us for the panel session.

Yours sincerely,

M B BUSH
Dean

RSVP 28 July 2005

Appendix V. Information Sheet for Panel Session

THE UNIVERSITY OF
WESTERN AUSTRALIA

*Graduate School of Education
School of Mechanical Engineering*

What Roles do Established Engineers Fulfil?

Research Project Information Sheet

In recent years, there has been an increasing emphasis on generic competencies or attributes in engineering education. This emphasis is reflected in the program accreditation criteria stipulated by Engineers Australia (EA).

We are currently supervising a Ph.D. candidate (Ms. Sally Male), whose research will develop and validate an instrument for assessing the generic competencies of recent engineering graduates. As a preliminary step in this process, she is conducting a panel session to extend on the work of James Trevelyan and others in defining the roles of established engineers.

You are invited to participate in this session as a university academic or engineering researcher. The panel will include approximately 11 others. Should you choose to participate, you will receive a set of guiding questions prior to attending your session.

Participation in this study is entirely voluntary. Even if you agree to participate at this stage, you are free to withdraw from the study at any time prior to or during the panel session. The session is anticipated to last approximately 90 minutes. The session will be recorded in both video and audio forms. This will be done to allow the information from the session to be transcribed. Your data, however, will remain confidential. All of the data will be stored in a secure digital format at the University of Western Australia. No names will be recorded in the database. ID numbers will be created to represent each participant at the data entry stage. Further, no reference to individual participants will be made in any resulting publications, unless you specifically indicate that you wish to be acknowledged in this way. You will receive a copy of the report produced.

If, having read this information sheet, you wish to participate in this research, please sign the attached consent form.

If you have any inquiries about the project, please contact either of the staff members listed below.

Chief Investigator/Principal Supervisor:

Dr. Elaine Chapman
Faculty of Education
The University of Western Australia
Crawley, Western Australia 6009
Fax: (08) 6488 1052
Telephone: (08) 6488 2384
Email: Elaine.Chapman@uwa.edu.au

Chief Investigator/Co-Supervisor:

Professor Mark Bush
School of Mechanical Engineering
The University of Western
Australia
Crawley, Western Australia 6009
Fax: (08) 6488 1026
Telephone: (08) 6488 3704
Email: dean@ecm.uwa.edu.au

Appendix VI. Consent Form for Panel Session

THE UNIVERSITY OF
WESTERN AUSTRALIA

*School of Mechanical Engineering
Graduate School of Education*

What Are The Roles That Established Engineers Fulfil?

Research Project Consent Form

I (the participant) have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I understand that all information provided is treated as strictly confidential and will not be released by the investigator unless required to by law. I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published.

Name: _____

Signature: _____

Date: _____

Do you wish to be acknowledged by name in any resulting publications and/or reports?

Yes ☐

No ☐

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

Appendix VII. Biographical Questionnaire for
Panel Session

Project to Develop an Instrument to Measure Generic Competencies of
Engineering Graduates: Phase 2. Research and Development Engineers
Panel Session
August 11, 2005

Biographical Questionnaire

The purpose of this questionnaire is to collect the demographic information about the participants in the panel session. Although names of participants will be acknowledged in resulting publications if requested, demographic information will not be matched to names at any time. Completion of each questionnaire item is voluntary.

Q1. Current Position

Q2. Qualifications¹ (Circle)		
1st Qualification	BE BSc BA MSc MEngSc MA MBA PhD	OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech	OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)	
Institution		
Country	AUSTRALIA	OTHER:

¹ adapted from Turley, R.T., "Essential Competencies of Exceptional Software Engineers", PhD Dissertation, Colorado State University, 1991, pp186

2nd Qualification	BE BSc BA MSc MEngSc MA MBA PhD		OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech		OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)		
Institution			
Country	AUSTRALIA	OTHER:	

3rd Qualification	BE BSc BA MSc MEngSc MA MBA PhD		OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech		OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)		
Institution			
Country	AUSTRALIA	OTHER:	

Q3. Other significant activities/experiences in your life which may contribute to your ideas (Circle)

SPORT TRAVEL RELIGION MUSIC PARENTING

OTHER: _____

Q4. Gender (Circle)

FEMALE

MALE

Q5. Number of years involved in engineering research and development: _____

Q6. Locations in which you have worked (Tick all applicable)

☐ WA

☐ AUSTRALIAN STATE OTHER THAN WA: _____

☐ COUNTRIES OTHER THAN AUS: _____

Q7. Types of research and development organizations in which you have worked (Tick all applicable)

☐ UNIVERSITY

☐ GOVERNMENT RESEARCH

☐ PRIVATE RESEARCH

Q8. Number of engineers in organizations where you have worked (Tick all applicable)

☐ <10

☐ 10 OR MORE AND LESS THAN 100

☐ 100 OR MORE

Q8. Industries in which you have experience ²	Tick all experienced	
	Research experience	Non-research experience
APPLIANCES AND ELECTRICALS		
BASIC METAL PRODUCTS		
CHEMICAL AND PETROLEUM		
COMMUNICATION INCLUDING TELSTRA		
CONSTRUCTION, CONTRACT, MAINTENANCE		
CONSULTING AND TECH SERVICES		
DEFENCE		
EDUCATION		
ELECTRICITY AND GAS SUPPLY		
FABRICATED METAL		
FOOD, BEVERAGE AND TOBACCO		
INDUSTRIAL MACHINERY		
MINING OR QUARRYING		
NON-METALLIC MINERALS		
OIL/GAS EXPLORATION/PRODUCTION		
PUBLIC ADMINISTRATION		
SCIENTIFIC EQUIPMENT		
STEEL PRODUCTION		
TRANSPORT AND STORAGE		
TRANSPORT EQUIPMENT		
WATER, SEWERAGE AND DRAINAGE		
WOOD AND PAPER PRODUCTS		
OTHER MANUFACTURING		
OTHER NON-MANUFACTURING		
OTHER _____		

² Classifications adopted from:

Association of Professional Engineers, Scientists and Managers, Australia (APESMA) (2004), APESMA / Engineers Australia Professional Engineers Remuneration Survey Summary Report
 Association of Professional Engineers, Scientists and Managers, Australia (APESMA) (2005), APESMA / Engineers Australia Professional Engineers Remuneration Survey Summary Report

Appendix VIII. Guiding Questions for Panel

Session

Guiding Questions for Panel Session on the Job of an Engineer involved in Research and Development

August 11, 2005

Sally Male

males01@student.uwa.edu.au

The panel session is to identify a list of tasks performed by established research and development engineers.

For the purposes of the panel session the job of an “**established research and development engineer**” will be any job in research and development in an engineering field and which would be given to someone

- with a 4-year university engineering degree and
- with a minimum of 5 and maximum of 20 years’ experience in research and development in engineering.

When reading the following questions please consider all the different types of established research and development engineering jobs which fit the above description and about which you have expert knowledge.

Guiding Questions for Discussion at the Panel Session

1. What are the outputs/objectives for which an established research and development engineer is paid i.e. which contribute to the organization in which the engineer works?
2. In addition to (1), what are the outputs/objectives which an established research and development engineer seeks to achieve in order to contribute to the success of the engineer’s career?
3. In addition to (1) and (2), what are the outputs/objectives which a research and development engineer seeks to achieve in order to contribute to the well-functioning of society?
4. What does a research and development engineer do to achieve each of the outputs/objectives identified in response to the above questions?

Note: “To have a successful career” has different meaning for different people. Question (2) seeks objectives which are intended, by the individual engineer, to improve the success of his or her career e.g. to optimize economic success, achievements or career satisfaction.

Appendix IX. Test Rubric for Survey 1

Questions for People Testing the Survey on Work Profiles and Required Competencies of Established Engineers

Thank you for testing the online questionnaire. Please record:

- the time it takes to complete each section
- mistakes
- ambiguous or unclear questions or response options
- comments on questions which are annoying/confusing, missing options, difficult to answer, etc
- any difficulties interacting with the online questionnaire, misleading titles/instructions, etc

The rubric below is to provide a prompt. Please use additional pages as needed.

	Time to Complete	Questions with typographical errors	Ambiguous/unclear questions or response options	Comments
Section I				
Section II				
Section III				
Section IV				
Section V				

Appendix X. Online Questionnaire for Survey 1

Section I of V: Graduate Attributes

Competencies of Engineering Graduates - Survey on Work and Competencies of Establis... Page 1 of 1

Competencies of Engineering Graduates

[Prospective Students](#) | [Current Students](#) | [Staff](#) | [Alumni](#) | [Visitors](#) | [About](#) Search UWA UWA Website for keywords...

[Welcome](#)
[Survey Questions](#)
[Survey Info Page](#)

Survey on Work Profiles and Required Competencies of Established Engineers

While completing this survey, please do NOT move back to the previous page after you click "NEXT", because your responses will be lost.

Unfortunately the radio buttons are misaligned with response options in some browsers. However, even if this occurs, it should be possible to complete the survey.

Section I of V: Graduate Attributes (2 brief questions)

- (1) **Is there a skill, attribute or area of knowledge that you would have liked to gain from your undergraduate engineering studies and did not?** If "Yes", please specify
- (2) **Is there a skill, attribute or area of knowledge that you have observed to be lacking in engineering graduates who have completed their degrees within the last 3 years?** If "Yes", please specify

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Section II of V: Demographics

Competencies of Engineering Graduates

[Prospective Students](#) | [Current Students](#) | [Staff](#) | [Alumni](#) | [Visitors](#) | [About](#) | [Search UWA](#) | [UWA Website](#) |

Welcome

[Survey Questions](#)

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Survey on Work Profiles and Required Competencies of Established Engineers

Section II of V: Demographics (16 questions)

To complete this survey, you must have between 5 and 20 years of 'engineering experience' since graduating from a 4-year, or longer, engineering degree. 'Engineering experience' may include work in a role for which you are suitable due to your engineering qualification, or time studying as a postgraduate student in an engineering-related field. Work may be as an engineer but may be in a different role in which the engineering qualification is relevant (e.g., patent evaluation, business development). The engineering degree may be from any university.

If you are not currently working in a role for which your engineering qualification makes you suitable (e.g. because you have family responsibilities), please answer questions about your work by referring to the time when you most recently worked in such a role.

If you have two engineering positions in different organizations, please select one of your positions to answer the questions about your current work.

- (1) **Number of years in your current position to the nearest year?**
- (2) **In which year did you complete your undergraduate engineering degree?**
- (3) **How many years of engineering experience (part-time or full-time) do you have since graduation,**

to the nearest
year?

- (4) Of your years of engineering experience, how many were part-time?

- (5) In which country did you complete your secondary education?

Australia

- (6) In which country were you awarded your undergraduate engineering qualification?

Australia

- (7) Was your undergraduate engineering qualification awarded by The University of Western Australia?

☐ No
☒ Yes

- (8) Did you do a combined/double degree? If so, which degree did you complete concurrently with Engineering?

☐ I did not do a combined degree
☐ Commerce/Economics
☐ Science (not Computer Science or Mathematics)
☒ Computer Science / Mathematics
☐ Arts
☐ Law
☐ (Other. Please specify)

- (9) In which disciplines of engineering do you have a degree?
(Select all that apply.)

☐ Aeronautical
☐ Agricultural
☐ Chemical
☐ Civil/Structural (inc. Building)
☐ Computer Systems
☒ Electrical
☐ Electromechanical/Mechatronics
☐ Electronic/Communication
☐ Environmental
☒ Geological
☐ Industrial/Production
☒ Manufacturing
☐ Materials
☒ Mechanical
☐ Mechatronics
☒ Metallurgical
☐ Mining

- ☐
- ☐ Naval architecture
- ☐ Nuclear
- ☐ Petroleum
- ☐ Software
- ☐ (Other. Please specify)
- (10) **Which of the following qualifications have you completed?**
(Select all that apply.)
- ☐ Bachelor of Engineering (Pass only)
- ☐ Bachelor of Engineering (Hons1)
- ☐ Bachelor of Engineering (Hons2A/2B/2)
- ☐ Bachelor of Engineering (Hons3)
- ☐ Masters in engineering or technical field
- ☐ MBA
- ☐ PhD or Doctorate in an engineering or technical field
- ☐ (Other. Please specify)
- (11) **Gender?**
- ☐ Female
- ☐ Male
- ☐ Other
- (12) **Do you have dependants for whom you are the primary carer?**
- ☐ No
- ☐ Yes
- ☐ I share the care and usually do half or less
- (13) **What is the total before tax annual income you earn from your engineering work, including e.g. bonuses, car, shares, superannuation contributions, in Australian dollars?**
- ☐ Less than \$51 000
- ☐ \$51 000 to \$100 000
- ☐ \$101 000 to \$150 000
- ☐ \$151 000 to \$200 000
- ☐ \$201 000 to \$250 000
- ☐ My income is in a different currency
- (14) **If your income is in a different currency, please specify the approximate amount and currency.**
- (15) **What is your age to the nearest number of years?**
- ☐ 25-29
- ☐ 30-34
- ☐ 35-39
- ☐ 40-44
- ☐ 45-49
- ☐ 50 or over

- (16) **Are you currently working in an engineering related area?**
- ☐ Yes
 - ☐ No. It has been less than four years since I was
 - ☐ No. It has been four or more years since I was

NEXT

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Section III of V: Work Context

Competencies of Engineering Graduates

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Survey on Work Profiles and Required Competencies of Established Engineers

Section III of V: Your Work Context (38 questions)

This section is to discover whether engineering jobs can be grouped into clusters with similar work contexts.

(Questions II-9 and III-2,3,4,5,7,8,17,19 are adapted from the Association of Professional Engineers, Scientists and Managers Australia / Engineers Australia "Spring 2005 Professional Engineer Remuneration Survey".)

- (1) **Which services are provided by your organization to its clients?**
(Select all that apply.)
- ☐ Consultancy services (e.g. design/project management)
 - ☐ Technical design/development/sales
 - ☐ Construction
 - ☐ Maintenance / asset management
 - ☐ Resource delivery/processing
 - ☐ Teaching
 - ☐ Research
 - ☐ Public authority / regulation
 - ☐ Provider of infrastructure (e.g. transport, roads, electricity, water, telecommunications)
 - ☐ (Other. Please specify)
- (2) **In which sectors are you employed?**
(Select all that apply. If you work in a sector which is a combination-type, then select all types in the combination.)
- ☐ Private sector - employee
 - ☐ Private sector - proprietor/director
 - ☐ National public service
 - ☐ National government instrumentality / GBE
 - ☐ State public service
 - ☐ State government instrumentality
 - ☐ Local government
 - ☐ University/tertiary institution
 - ☐ School including technical colleges (TAFE)
 - ☐ (Other. Please specify)
- (3) **Do you work for a consulting engineering**
- ☐ No

- firm?
- (4) **In which of the non-manufacturing industries are you mainly engaged?**
(Select all that apply.)
- ☐ Yes
 - ☐ Consulting/technical services
 - ☐ Construction/contract/maintenance
 - ☐ Mining/quarrying
 - ☐ Oil/gas exploration/production
 - ☐ Electricity/gas supply
 - ☐ Water/sewerage/drainage
 - ☐ Communications (inc. Telstra)
 - ☐ Defence
 - ☐ Public administration (Federal/State/Local)
 - ☐ Transport/storage
 - ☐ Education
 - ☐ (Other. Please specify)
- (5) **In which of the manufacturing industries are you mainly engaged?**
(Select all that apply.)
- ☐ Food/beverage/tobacco
 - ☐ Wood/furniture / paper products
 - ☐ Chemical/petroleum products
 - ☐ Non-metallic mineral products
 - ☐ Basic metal products
 - ☐ Steel production
 - ☐ Fabricated metal products
 - ☐ Transport equipment (inc. motor vehicles)
 - ☐ Photographic/scientific equipment
 - ☐ Appliances / electrical equipment (inc. electronic equipment)
 - ☐ Industrial equipment / machinery
 - ☐ (Other. Please specify)
- (6) **For how many years has your organization provided its main current service or product?**
- ☐ Less than 1
 - ☐ 1 to 3
 - ☐ More than 3
- (7) **How many employees are employed by your company/organization?**
- ☐ 0 to 10
 - ☐ 11 to 50
 - ☐ 51 to 100
 - ☐ 101 to 500
 - ☐ Over 500
- (8) **How many professional engineers (with at least a 4 year engineering degree) are employed by your organization?**
- ☐ Less than 11
 - ☐ 11 to 100
 - ☐ 101 to 500
 - ☐ Over 500
- (9) **To what extent are the locations of the users of your organization's products/services local or global?**
- ☐ Users are in one or two states/provinces in one country only
 - ☐ Users are in more than two states/provinces in one country only
 - ☐ Users are in two to four countries

- ☐
- ☒ Users are in more than 4 countries.
- (10) In which country do you spend most of your work time? Australia
- (11) If you spend most of your work time in Australia, which state/territory? ACT
- (12) In how many countries have you worked during the past 2 years?
- ☐ 1
- ☒ 2
- ☐ 3 or more
- (13) What is the organizational structure of your organization?
- ☐ Mainly flat
- ☒ More flat than hierarchical
- ☐ Mixed
- ☐ More hierarchical than flat
- ☐ Mainly hierarchical
- (14) How are the people in your organization grouped?
(Select all that apply.)
- ☐ By function/activity
- ☒ By engineering discipline
- ☐ By project
- ☒ By product / service market
- ☐ By geographic location
- ☒ As a matrix (combination of departments or divisions superimposed on a functional structure)
- ☐ Unclear to me
- ☐ (Other. Please specify)
- (15) Please enter your organization code.
(This code should not identify your company name. The code is to alert us to multiple responses from the same organization. This will improve our statistical analysis without identifying organizations. If you have not received a code for from someone else in your organization, then choose any word with 4 to 10 letters to be your organization code. If you recommend the survey to others in your organization, then please ask them to enter the same organization code.)

- (16) **What is your official position title?**
- (17) **What is the status of your current or most recent main engineering job?**
- (18) **Is your role technical?**
- (19) **What are the key responsibilities in your position?**
(Select all that apply.)
- (20) **For how many people are you responsible in total (directly or indirectly)?**
- (21) **How many people do you supervise directly?**
- (22) **What is the pace of your daily work?**
(Select the best approximation.)
- (23) **What is the nature of your work schedule?**
- ☐ Full-time
- ☐ Part-time
- ☐ Self-employed / proprietor/director
- ☐ Hourly contract employee
- ☐ (Other. Please specify)
- ☐ Yes, mostly technical
- ☐ Yes, partly technical
- ☐ No, or hardly at all
- ☐ Construction supervision
- ☐ Design of equipment/processes (not product design)
- ☐ Management
- ☐ Production/quality/maintenance
- ☐ Project study/analysis
- ☐ Research/development (inc. product design/development)
- ☐ Sales/marketing
- ☐ Teaching/training
- ☐ (Other. Please specify)
- ☐ 0 to 9
- ☐ 10 to 19
- ☐ 20 to 49
- ☐ 50 to 99
- ☐ 100 to 499
- ☐ Over 499
- ☐ 0 to 4
- ☐ 5 to 9
- ☐ 10 or more
- ☐ Slow
- ☐ Fairly slow
- ☐ Moderate
- ☐ Fairly fast
- ☐ Fast
- ☐ At my discretion providing I can be contacted and deadlines are met
- ☐ Fairly regular office hours with flexibility to work early or late without overtime pay
- ☐ Regular office hours and paid overtime
- ☐ Rostered shifts, returning home daily
- ☐ Rostered fly-in fly-out or fly-in fly-out on variable schedules as required to complete work
- ☐

- (Other. Please specify)
- (24) **What type of deadline governs the majority of your work?**
(Select the best approximation.)
- ☐ Broad
☒ Specific but flexible
☐ Specific and strict
- (25) **What level of autonomy do you have in your work?**
(Select the best approximation.)
- ☐ I am at the most senior level in the organization
☒ I receive few or no instructions but there are people in the organization more senior than me
☐ I receive broad instructions
☐ I receive detailed instructions but I am left to work autonomously
☐ I receive detailed instructions and have little or no autonomy
- (26) **Are new procedures set up for each different job in your organization (e.g for record keeping, communications, information management, quality control etc)?**
- ☐ Yes, different procedures are set up for different jobs
☒ Yes sometimes.
☐ No, procedures are the same for all jobs
☐ No, we rarely use procedures
- (27) **What percentage of your work time is spent in regional, remote or offshore locations?**
- ☐ 0-33%
☒ 34-66%
☐ 67-100%
- (28) **In which of the following types of workplace do you spend more than 10% of your work time?**
(Select all that apply.)
- ☐ At home
☒ In offices on or off site but not at home
☐ In laboratories or workshops
☐ Offshore or on site and not in an office
- (29) **How often do you need to learn new tasks in your job?**
(Please select the best approximation.)
- ☐ Annually
☒ Monthly
☐ Three or more times a month
- (30) **Which of the following would result if you performed your job poorly?**
(Select all that apply.)
- ☐ Loss of time / financial cost / loss of a client or project
☒ Lifestyle cost to society / cost to the economy / injury but not death to up to 5 people
☐ Local environmental cost / health cost or injury to more than 5 people
☐ Loss of human life / large scale environmental cost
- (31) **To achieve your work goals, with**
- ☐ Fewer than 5
☒ 6 to 10

- approximately how many people do you need to communicate on average per day?**
- ☐ 11 to 15
- ☐ More than 15
- (32) **With whom must you communicate to achieve your work goals?**
(Select all that apply.)
- ☐ Engineers in your discipline
- ☐ Engineers in disciplines different from yours
- ☐ Other people with scientific backgrounds (e.g. geologists/architects/doctors)
- ☐ Drafters
- ☐ Lawyers
- ☐ Politicians
- ☐ IT professionals
- ☐ Accountants
- ☐ Purchasing officers
- ☐ Technicians/Tradespeople/Labourers
- ☐ Community members
- ☐ Clients/users
- ☐ Your organization's marketing people
- ☐ Suppliers
- ☐ Journalists
- (33) **Which of the following groups are represented in most of the teams on which you work?**
(Select all that apply.)
- ☐ Women
- ☐ People indigenous to the country in which you are working
- ☐ People working outside the country in which you are working
- ☐ People who did most of their schooling outside the country in which you are based
- (34) **What percentage of your work time is spent working alone (except perhaps communicating by email) in an average working day?**
- ☐ 0-33%
- ☐ 34-66%
- ☐ 67-100%
- (35) **Which of the following types of communication do you use in your work?**
(Select all that apply.)
- ☐ Interactive unstructured communication/conversation (e.g. with team members, telephone conversations)
- ☐ Meetings (chairing or participating)
- ☐ Public fora
- ☐ Interviews (as interviewer or interviewee)
- ☐ Short notes / emails / online communication etc
- ☐ Oral presentations / speeches / seminars / lectures / workshops (as speaker)
- ☐ Sketches / technical drawings / flow

- ☐ charts / schematic diagrams / ladder diagrams / graphs
☐ Written reports / technical papers
☐ Business letters
☐ Strategic plans / business plans
☐ Tenders (calling and evaluating, or submitting) / specifications / budgets / quotes / schedules
☐ Standards / codes / regulations / legislation
☐ Accounting / financial records
☐ Models / simulations / prototypes
☐ Applications (for e.g. approval, financial support, sponsorship, jobs, grants, accreditation) (as applicant or assessor)
☐ Manuals / procedures / instructions
☐ Record of calculations/analysis
☐ Journal or record of work/progress/thoughts/outcomes
☐ (Other. Please specify)
- (36) On average, how many projects do you work on at once?
- ☐ None
☐ 1
☐ 2
☐ More than 2
- (37) With which of the following do you agree?
(Select all that apply.)
- ☐ My work is valued in my organization
☐ I influence decisions in my organization
☐ My organization provides me with professional development opportunities such as courses or conference leave
☐ My job provides me with challenge and opportunity to learn on the job
☐ I have promotional opportunities in my organization
☐ My job is secure
- (38) If you work on projects, in general at what stage in the project do you join the project team?
- ☐ I do not work on projects
☐ Early
☐ Mid to late

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Section IV of V: Tasks

Survey on Work Profiles and Required Competencies of Established Engineers

Section IV of V: Your Work Tasks (12 work areas with tasks from which to select)

This section is to discover whether the jobs of established engineers can be grouped into clusters of jobs involving similar tasks.

To do your current job well, which of the following tasks must you do?

(The tasks are adopted from National Generic Competency Standards Stage 2 Competencies available at <http://www.engineersaustralia.org.au/membership/professional.html>)

(1) Engineering Practice

(Select the tasks that you must do to do your current job well.)

- ☐ Identify opportunities to apply engineering to solve problems **Form teams of people (i.e. identify and recruit team-members)**
- ☐ Develop engineering solutions to identified problems
- ☐ Identify constraints on potential engineering solutions
- ☐ Publish outcomes of innovation in reports / professional papers
- ☐ No tasks in this category

(2) Planning/design

(Select the tasks that you must do to do your current job well.)

- ☐ Interpret/scope design requirements
- ☐ Prepare concept proposals for designs
- ☐ Seek advice on latest technology to inform designs
- ☐ Implement planning and design processes
- ☐ Review designs to achieve acceptance
- ☐ Prepare and maintain documentation during design processes
- ☐ Validate designs
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(3) Project Engineering / Engineering Project Management

(Select the tasks that you must do to do your current job well.)

- ☐ Develop and manage project integration (e.g. manage communication across the project with all stakeholders)
- ☐ Scope projects
- ☐ Quantify the engineering tasks

- ☐ required for projects
- ☐ Quantify the human resources required for projects
- ☐ Quantify the physical resources, equipment and arrangements required for projects
- ☐ Define parameters for environmental management plans for projects
- ☐ Manage people working on projects (e.g. performance targets)
- ☐ Manage physical resources within projects
- ☐ Manage risk related to projects (e.g. quality/safety/finance)
- ☐ Manage costs for projects
- ☐ Manage procurement for projects
- ☐ Manage progress on projects
- ☐ Supervise progress on projects
- ☐ Finalise projects
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(4) Engineering Operations

(Select the tasks that you must do to do your current job well.)

- ☐ Plan operations/systems
- ☐ Manage processes within operations/systems
- ☐ Manage maintenance and assets within operations/systems
- ☐ Manage people working on operations/systems (e.g. performance reviews)
- ☐ Measure and document engineering operations/systems
- ☐ Manage environmental performance of engineering operations/systems
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(5) Business Management/Development

(Select the tasks that you must do to do your current job well.)

- ☐ Contribute to engineering business strategies
- ☐ Develop client relationships
- ☐ Identify clients' needs
- ☐ Manage resources for the business
- ☐ Manage people across the organization (e.g. training and development)
- ☐ Manage knowledge in the organization
- ☐ Manage business suppliers for the business
- ☐ Manage business information
- ☐ Monitor engineering business performance
- ☐ Prepare tender submissions
- ☐ Estimate costs

(6) **Materials/Components/Systems or Sourcing/Estimating of Materials/Components**

(Select the tasks that you must do to do your current job well.)

- ☐ Manage contracts
- ☐ Manage costs across the organization
- ☐ Manage risks and contingencies across the organization (e.g. safety, quality, environmental issues)
- ☐ Protect intellectual property
- ☐ Manage change in organizational structure/procedures (**not** technical change)
- ☐ No tasks in this category
- ☐ (Other. Please specify)

- ☐ Determine engineering requirements
- ☐ Design/develop materials/components/systems
- ☐ Define processes to prepare materials/components/systems for use in projects/operations
- ☐ Manage uses of materials/components/systems within projects/operations
- ☐ Manage the recovery/reuse/disposal of materials/components/systems
- ☐ Plan sources for materials
- ☐ Estimate materials
- ☐ Procure materials/resources / coordinate suppliers
- ☐ Prepare materials/components/systems for use in projects/operations
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(7) **Environmental Management**

(Select the tasks that you must do to do your current job well.)

- ☐ Determine existing environmental conditions
- ☐ Establish stakeholders' expectations
- ☐ Review existing environmental conditions against stakeholders' expectations
- ☐ Develop and rank strategies to achieve sustainable development
- ☐ Implement/monitor/evaluate strategies for environmental management / sustainable development
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(8) **Investigation and Reporting**

(Select the tasks that you must do to do your current job well.)

- ☐ Respond to / identify problems
- ☐ Plan / carry out investigations
- ☐ Draw conclusions from investigations and make recommendations

(9) Research/Development/Commercialisation

(Select the tasks that you must do to do your current job well.)

- ☐ No tasks in this category
- ☐ (Other. Please specify)
- ☐ Identify opportunities for new or improved processes/products
- ☐ Identify the resources required for research/development
- ☐ Initiate concept development
- ☐ Gain commitment to research and development proposals
- ☐ Undertake research / ensure research is undertaken
- ☐ Publish research results
- ☐ Protect intellectual property / secure patents
- ☐ Collaborate in the commercialisation of research outcomes
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(10) Change / Technical Development (e.g. Improvement of Products or Services Provided by your Organization)

(Select the tasks that you must do to do your current job well.)

- ☐ Participate in planning the introduction of technical change
- ☐ Develop technically creative and flexible approaches/solutions
- ☐ Manage emerging technical challenges/opportunities
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(11) Technical Sales/Promotion

(Select the tasks that you must do to do your current job well.)

- ☐ Maintain market insight
- ☐ Seek to understand clients and their needs
- ☐ Build relationships with clients
- ☐ Identify sales opportunities
- ☐ Apply product knowledge to meet clients' requirements/concerns
- ☐ Promote technical capability of products/systems
- ☐ Seek clients' feedback
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(12) Teaching

(Select the tasks that you must do to do your current job well.)

- ☐ Prepare/develop course materials
- ☐ Promote courses
- ☐ Coordinate courses
- ☐ Present courses / facilitate/guide individual or group learning
- ☐ Demonstrate/supervise development of practical skills/techniques
- ☐ Assess individuals' learning outcomes
- ☐ Evaluate courses
- ☐ No tasks in this category
- ☐ (Other. Please specify)

(13) Is there another broad area of work that it is part of your job?

(Please name and list tasks.)

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Section V of V: Competencies

V.1. Group Effectiveness / Teamwork

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Survey on Work Profiles and Required Competencies of Established Engineers

Section V of V: Competencies: Page 1 of 6 (4 questions)

This section is to discover which competencies are important. The competencies are listed under six headings.

(Many of the competencies are adapted from Engineers Australia National Generic Competency Standards - Stage 1 Competency Standards for Professional Engineers, Engineers Australia Accreditation Board, Bradley (2005))

Group effectiveness/teamwork

How important is each of the following to doing your job well?

1=not needed
5=critical

(1) Interacting with people from diverse cultures / backgrounds	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(2) Interacting with people in diverse disciplines/professions/trades	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(3) Mentoring/coaching co-workers	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(4) Working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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V.2. Communication

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Section V of V: Competencies: Page 2 of 6 (8 questions)

Communication

How important is each of the following to doing your job well?

1=not needed
5=critical

(1) Communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(2) Managing own communications (e.g. keeping up to date and complete, following up)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(3) Negotiating / asserting/defending approaches/needs	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(4) Presenting clearly and engagingly (e.g. speaking, lecturing)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(5) Speaking and writing fluent English	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(6) Using effective graphical communication (e.g. reading drawings)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(7) Using effective verbal communication (e.g. giving instructions, asking for information, listening)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(8) Working effectively in a second country	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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V.3. Creative Thinking / Problem-Solving

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Section V of V: Competencies: Page 3 of 6 (21 questions)

Creative thinking / problem solving

How important is each of the following to doing your job well?

1=not needed

5=critical

(1) Applying mathematics, science or technical engineering theory or working from first principles	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(2) Appreciating aesthetic features of design	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(3) Being familiar with complete life-cycle of projects/programs/products	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(4) Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in your discipline of engineering (e.g. ability to recognise unrealistic results)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(5) Evaluating / advocating for / improving maintainability	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(6) Evaluating / advocating for / improving manufacturability	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(7) Evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(8) Evaluating reliability / potential failures	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

- (9) Evaluating the impact of engineering solutions in the social/cultural/political contexts (*local/global*) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (10) Generalising/abstracting concepts ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (11) Modelling/simulating/prototyping and recognising the limitations involved ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (12) Solving problems (*e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs*) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (13) Sourcing/understanding/evaluating information ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (14) Thinking critically to identify potential possibilities for improvements ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (15) Thinking laterally / using creativity/initiative/ingenuity ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (16) Trying new approaches/technology / capitalising on change / initiating/driving change ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (17) Using 'simultaneous engineering design and development' / 'integrated product and process design' / 'collaborative engineering' ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (18) Using 3D spatial perception or visualisation (*e.g. visualising various perspectives*) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (19) Using a systems approach ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (20) Using design methodology (*e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating*) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (21) Using research / experimentation techniques / scientific method ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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V.4. Organizational Effectiveness / Leadership

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Section V of V: Competencies: Page 4 of 6 (17 questions)

Organizational effectiveness / leadership

How important is each of the following to doing your job well?

1=not needed

5=critical

(1) Actively promoting diversity within your organization (e.g. culture, religion)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(2) Applying familiarity with risk/liability/legislation/standards/codes / IP issues	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(3) Applying familiarity with the different functions in your organization and how these interrelate	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(4) Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(5) Chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(6) Coordinating the work of others	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(7) Engaging in entrepreneurship / innovation / identifying and commercialising opportunities	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(8) Evaluating marketing issues / applying a customer focus	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(9) Evaluating / advocating for / improving health and safety issues	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(10) Focusing on your organization's needs	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(11) Leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(12) Making decisions within time and knowledge constraints	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(13) Managing (e.g. projects/programs/contracts/people/strategic	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

planning/performance/change)

- (14) **Networking (i.e. building/maintaining personal/organizational networks)** ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (15) **Supervising work/people** ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (16) **Taking considered risks** ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (17) **Understanding social and political dimensions of workplaces** ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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**V.5. Self-Management / Personal Style / Lifelong
Learning**

Competencies of Engineering Graduates

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Survey on Work Profiles and Required Competencies of Established Engineers

Section V of V: Competencies: Page 5 of 6 (7 questions)

Self management / personal style / life-long learning

How important is each of the following to doing your
job well?

1= not needed

5= critical

(1) Being positive/enthusiastic/motivated	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(2) Engaging in active citizenship
(e.g. being involved in the local /
national or international
community / engaging in public
debates)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(3) Having an action orientation (e.g.
avoiding delays, maintaining a
sense of urgency)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(4) Keeping up to date with current
events / contemporary business
concepts / engineering
research/techniques/materials	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(5) Managing information/documents	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(6) Managing personal and
professional development (e.g.
self-directed/independent
learning; learning from
advice/feedback/experience;
thinking reflectively and
reflexively)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
(7) Managing self (e.g.
time/priorities / quality of
output /
motivation/efficiency/emotions /
work-life balance/health)	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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V.6. Work-Related Dispositions and Attitudes

Competencies of Engineering Graduates - Survey on Work and Competencies of Establish... Page 1 of 2

Competencies of Engineering Graduates

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Survey on Work Profiles and Required Competencies of Established Engineers

Section V of V: Competencies: Page 6 of 6 (7 questions)

Work-related dispositions and attitudes

How important is each of the following to doing your
job well?

1=not needed
5=critical

- (1) Acting within exemplary ethical standards ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (2) Being committed to doing your best ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (3) Being concerned for the welfare of others in your organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (4) Being concerned for the welfare of the local, national and global communities ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (5) Being loyal to your organization (e.g. representing it positively) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (6) Demonstrating honesty (e.g. admitting one's mistakes, giving directors bad news) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5
- (7) Presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful) ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

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<http://ceg.ecm.uwa.edu.au/survey>

2/04/2007

Appendix XI. Calls for Participants for Survey 1

1. In Engineering WA Newsletter

Published in Engineering WA Newsletter of the WA Division of Engineers Australia, July 2006, p.2

CALLING ENGINEERS WITH 5 TO 20 YEARS' EXPERIENCE – The Competencies of Engineering Graduates (CEG) Project

The University of Western Australia is developing an instrument to profile the generic competencies of engineering graduates.

If you have 5 to 20 years' engineering experience since graduation, your support completing an online questionnaire would be greatly appreciated. For further information and to complete the survey please visit www.ceg.ecm.uwa.edu.au. Participants have the opportunity to enter a draw to win an ipod.

2. In Newsletter of Engineering Graduates

Association

Published in *Newsletter* Engineering Graduates Association, The University of Western Australia, October 2005, p.1

Competencies of Engineering Graduates (CEG)

The Faculty of Engineering, Computing and Mathematics is undertaking an interdisciplinary project to develop an instrument for surveying workplace supervisors to profile the generic competencies of engineering graduates. This will help to keep engineering courses aligned with industry requirements. The study is being conducted as a Ph.D. project by Ms Sally Male, under the supervision of Professor Mark Bush, Dean, Faculty of Engineering, Computing and Mathematics, and Dr. Elaine Chapman, Lecturer, Graduate School of Education.

The project will use quantitative methods to complement the extensive work on engineering competencies provided by organizations such as Engineers Australia.

Industry participation is essential to the success of this project. We are grateful to the project's advisory committee and the nine participants in the first panel session, held in August. We will soon be seeking "established" engineers, that is, with 5 to 20 years experience to participate in the first large-scale survey. Subsequent surveys will need different categories of respondents: senior engineers and finally graduates and their supervisors. The surveys will be implemented online. If you or your organization might be able to assist with the recruitment of voluntary participants, please contact Sally Male for further information. males01@student.uwa.edu.au ceg.ecm.uwa.edu.au/

3. In *The Engineering Essential*

Published in *The Engineering Essential* (previously *Newsletter*), Engineering Graduates Association, The University of Western Australia, June 2006, p.2

Survey on Engineering Work and Generic Competencies

CALLING ENGINEERS WITH 5 TO 20 YEARS' EXPERIENCE. The Competencies of Engineering Graduates (CEG) Project will inform us about the continuous improvement of engineering courses. Your support by completing an online questionnaire would be greatly appreciated. Please see our previous newsletter October 2005 or visit www.ceg.ecm.uwa.edu.au

4. In Newsletter of the WA Section of the Institute of Electrical and Electronic Engineers

Published in Newsletter of the WA Section of the Institute of Electrical and Electronic Engineers, October 2006

Competencies of Engineering Graduates Project

The Faculty of Engineering, Computing and Mathematics at The University of Western Australia is developing an instrument to profile the generic competencies of engineering graduates. The instrument will help universities to align engineering courses with industry requirements.

The instrument development is being conducted as a Ph.D. project by Ms Sally Male BE(Hons)(Electrical), under the supervision of Dr Elaine Chapman, Associate Dean Research, Graduate School of Education, and Professor Mark Bush, Dean, Faculty of Engineering, Computing and Mathematics.

The first survey in the CEG Project is to discover whether the jobs of established engineers can be grouped into clusters requiring similar competencies. This survey is nearing completion.

For further information visit

<http://ceg.ecm.uwa.edu.au>

Appendix XII. Letter of Invitation to Participate in Survey 1

Office of the Dean (M017)

Faculty of Engineering, Computing and Mathematics
The University of Western Australia
35 Stirling Highway, Crawley, WA 6009
Phone: +61 8 6488 3704
Fax: +61 8 6488 1026
CRICOS No: 00126G
Email: dean@ecm.uwa.edu.au
Professor Mark B Bush

26 July 2006

<Title> <Name>
<Position>
<Organization>
<Postal Address>

Dear <>,

Invitation to Complete a Survey in the Competencies of Engineering Graduates (CEG) Project

The Faculty of Engineering, Computing and Mathematics is undertaking a project to develop methods for surveying employers to produce a profile of UWA engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. If such a profile indicates that certain competencies are lacking or deficient in our graduates, then we will be able to make methodical and justifiable adjustments to the range of units of study that deal with those competencies.

The study is being conducted as a Ph.D. project by Ms. Sally Male, under the supervision of Dr. Elaine Chapman of the Graduate School of Education, and me. A fundamental component of the project involves identifying the key competencies required of engineering graduates. To achieve this we need the assistance of practicing engineers, and I therefore seek your help in achieving success in this very important project.

I would like to invite you to complete an online survey on the work and competencies of established engineers. The survey will help us to determine whether established engineers' jobs can be grouped into clusters of tasks that require similar groups of weighted competencies.

Volunteers will have 5 to 20 years of 'engineering experience' since graduating from a 4-year engineering degree. 'Engineering experience' may include work in a role for which you are suitable due to your engineering qualification, or time studying as a postgraduate student in an engineering-related field. **Experience is most likely to be as an engineer but may be in a different role in which your engineering qualification is relevant.** Your graduation date suggests that you would be suitable to participate.

Further information and the survey questions can be found at
www.ceg.ecm.uwa.edu.au

The participation of volunteers will be essential to the success of this project. We will be most grateful if you can spare some time to complete the survey and inform other 'established engineers' of the opportunity. In appreciation, I am offering volunteers who complete the survey before September 1st, 2006, the opportunity to receive a report on the survey results and entry in a draw to win an ipod.

Thank you for considering this request.

Yours sincerely,

M B BUSH
Dean

Appendix XIII. Information Sheet for Survey 1

Work Profiles and Required Competencies of Established Engineers

This survey of established engineers is a component of the Competencies of Engineering Graduates (CEG) Project. Sally Male (PhD candidate, UWA) is conducting this research under the supervision of Professor Mark Bush (Dean, Faculty of Engineering, Computing and Mathematics), and Dr Elaine Chapman (Associate Dean - Research, Faculty of Education). The ultimate goal of the project is to develop methods for surveying employers to produce a profile of UWA engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. If such a profile indicates that certain competencies are lacking or deficient in our graduates, then we will be able to make methodical and justifiable adjustments to the range of units of study that deal with those competencies.

We require the expert opinions of practicing engineers to achieve success in this very important project. The purposes of the current survey are to:

- 1) Identify clusters of engineering jobs based on their work task profiles;
- 2) Determine the relative importance of different types of competencies across these job clusters; and
- 3) Examine whether the importance of different types of competencies within these clusters varies with demographic factors such as gender and disciplinary background.

Who is Invited to Complete the Survey?

To complete this survey, you must have between 5 and 20 years of 'engineering experience' since graduating from a four-year engineering degree. 'Engineering experience' may include work in a role for which you are suitable due to your engineering qualification, or time studying as a postgraduate student in an engineering-related field. Work may be as an engineer but may be in a different role in which the engineering qualification is relevant (e.g., work related to patents). The engineering degree may be from any university.

What is Involved for Volunteers Completing the Survey?

The survey should take approximately 20 minutes to complete. Should you choose to complete the survey, you will remain completely anonymous. The survey will ask some general questions about you and your background, about the kinds of work tasks that you do, and about the types of competencies you consider most important for doing the kind of work that you do.

Offer to Enter a Draw to Win an Ipod and Receive a Report on the Survey Results

Before August 30, 2006, participants who complete the survey will be invited to enter a draw to win a 30 GB ipod and to receive a report on the results of the survey. To accept this offer, please enter your email addresses when prompted on completing the survey. As this information will be submitted and stored separately from the survey responses, it will be impossible to match these at any time. The draw for the ipod will be in the Dean's Office, Faculty of Engineering, Computing and Mathematics, UWA, at 10am on Friday September 1, 2006.

Consent to Participate

Completion of the online survey is considered evidence of consent to participate in the study. You are free to withdraw from the study at any time by exiting the survey.

Questions on the Survey

Questions are welcome. Please contact one of the researchers either by e-mail or by telephone with any questions you have about this survey or about the CEG project (contact details below).

Complaints

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively, to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703).

Contact Details for the Researchers

Professor Mark Bush, Dean, Faculty of Engineering, Computing and Mathematics, MBDP M017, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (Telephone: 6488 3704, Fax: 6488 1026, Email: mark.bush@uwa.edu.au)

Dr Elaine Chapman, Associate Dean - Research, Faculty of Education, MBDP M428, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (Telephone: 6488 2384, Fax: 6488 1052, Email: elaine.chapman@uwa.edu.au)

Ms Sally Male, PhD Candidate, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (MBDP M050, Fax: 6488 1026, Email: males01@student.uwa.edu.au).

Appendix XIV.

Online Information Page for Survey 1

Competencies of Engineering Graduates - Information Page for Survey on Work and Co... Page 1 of 3

Competencies of Engineering Graduates

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Information on the Survey

Work Profiles and Required Competencies of Established Engineers

This survey of established engineers is a component of the Competencies of Engineering Graduates (CEG) Project. Sally Male (PhD candidate, UWA) is conducting this research under the supervision of Professor Mark Bush (Dean, Faculty of Engineering, Computing and Mathematics), and Dr Elaine Chapman (Associate Dean - Research, Faculty of Education). The ultimate goal of the project is to develop methods for surveying employers to produce a profile of UWA engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. If such a profile indicates that certain competencies are lacking or deficient in our graduates, then we will be able to make methodical and justifiable adjustments to the range of units of study that deal with those competencies.

We require the expert opinions of practicing engineers to achieve success in this very important project. The purposes of the current survey are to:

- 1) Identify clusters of engineering jobs based on their work task profiles;
- 2) Determine the relative importance of different types of competencies across these job clusters; and
- 3) Examine whether the importance of different types of competencies within these clusters varies with demographic factors such as gender and disciplinary background.

Who is Invited to Complete the Survey?

To complete this survey, you must have between 5 and 20 years of 'engineering experience' since graduating from a 4 year, or longer, engineering degree. 'Engineering experience' may include work in a role for which you are suitable due to your engineering qualification, or time studying as a postgraduate student in an engineering-related field. Work may be as an engineer but may be in a different role in which the engineering qualification is relevant (e.g., work related to patents). The engineering degree may be from any university.

What is Involved for Volunteers Completing the Survey?

The survey should take approximately 20 to 30 minutes to complete. Should you choose to complete the survey, you will remain completely anonymous. The survey will ask some general questions about you and your background, about the

Appendix XV. Data Coding Decisions for Survey 1

Responses to Section III Q2 Question on Sector

Recorded Responses with Decisions on How to Record Them

Private – employee

Private - proprietor/director

National PS

National GBE

State PS

State GBE

Local gov

Uni

TAFE

Other: contractor – was decided this is same as proprietor/director

Private sector - employee, Private sector - proprietor/director (1,2)

Private sector - proprietor/director, State public service (2,3)

Private sector - employee, National public sector (1,3)

Private sector – employee, University/tertiary institution (1,6)

Private sector - proprietor/director, National government instrumentality / GBE (2,4)

State public service, State government instrumentality (3,4)

Private sector – employee, National public sector, State public service(1,3)

Private sector - proprietor/director, University/tertiary institution (2,6)

Other: Profit sharing – was decided this is same as private – employee

- *Local government* was combined with *other government* because there were only 2 responses in this category
- If a government organization is one of many clients then someone who works in the private sector would not list the government sector. If the main organization in which the person works is in the government sector, despite being private then they would list both. Therefore, anyone listing both will have selection changed to *government*.
- Similarly *private employee* and *employer* was called *private employee*.
- Two people selected both *State public service* and *state government instrumentality*. To decide how to code this other organizations with the same organization code (*Jim* or *Jimm*) were considered: Some had selected *State public service* and some had selected *State government instrumentality*. Therefore, *National public service, State public service, State government Instrumentality* and *National government instrumentality/GBE* were combined.

Responses to Section III Q4 and Q5 Questions on Industry

Decisions on How to Record Individual Responses

- *Other: Boat construction* was replaced with *Transport equipment* which the person also selected
- *[OTHER]: ship building* was replaced with *Transport equipment*
- *[OTHER]: Automotive engine research* was replaced with *Transport equipment*

- *Other: Prototyping* was replaced with *Consulting/technical services*
- *[OTHER]: instrumentation and control* was replaced with *Consulting/technical services*
- *[OTHER]: Wireless* was replaced with *Communications*
- *[OTHER]: Electronics Materials* was replaced with *Appliances / electrical equipment (inc. electronic equipment)*
- *[OTHER]: Water Treatment - Potable Water* was replaced with *Water/sewerage drainage* which the person also selected
- *[OTHER]: mining equipment components* was replaced with *Mining/quarrying* which the person also selected
- *[OTHER]: structural* was ignored as being a manufacturing industry because the same person selected *Consulting* and not *Construction* as a non-manufacturing industry.
- *[OTHER]: aviation* and *Other: aerospace* were replaced with *Transport equipment* (which the person had also selected).
- *[OTHER]: Plastic Bottles (Cosmetics & Pharmaceuticals)* was replaced with a new category: *Plastics*
- *[OTHER]: Rail and Mining* was replaced with *Transport/storage* and *Mining/quarrying*
- *Construction/contract/maintenance, Mining/quarrying, Water/sewerage/drainage, Transport/storage, [OTHER]: Infrastructure - Infrastructure* was ignored because it was covered by *Construction/contract/maintenance*
- *Software products and IT* was replaced with a new category *IT/Software*
- *[OTHER]: Commercial Aerospace* was replaced with *Transport/storage* (Note *Transport/storage* is under non-manufacturing industries and *Transport equipment (inc. motor vehicles)* is under manufacturing industries.)
- *10, [OTHER]: boat design* was replaced with *Transport equipment*
- *Mining/quarrying, [OTHER]: refining – refining* was replaced by *Basic metal products* which the person also selected
- *Medical* was replaced with new category: *Medical/biotechnology/pharmaceutical*
- *Biotechnology* was replaced with new category: *Medical/biotechnology/pharmaceutical*
- *pharmaceutical* was replaced with *Medical/biotechnology/pharmaceutical*
- *Consulting/technical services, Mining/quarrying, [OTHER]: Environmental – Environmental* was considered to be included in *Consulting*
- *Other: Security* was replaced with *Consulting/technical services*, although the person did not select it
- *Other: Patent advice* was replaced with *Consulting/technical services* which the person also selected
- *Other: Waste management* was replaced with *Consulting/technical services* which the person also selected
- *Consulting/technical services, [OTHER]: Minerals processing (Alumina) – replaced Minerals processing* with *Basic metal products*, although the person did not select it
- *Chemical/petroleum products, Transport equipment (inc. motor vehicles), [OTHER]: Environmental –* was decided to assume that the other two selections sufficiently cover *environmental* here
- *[OTHER]: IC chip product* was replaced with *Appliances / electrical equipment (inc. electronic equipment)*
- *[OTHER]: semiconductor* was replaced with *Appliances / electrical equipment (inc. electronic equipment)*
- *[OTHER]: gases - industrial, cryogenic, etc* was replaced with *Chemical/petroleum products*

- *Photographic/scientific equipment, Appliances / electrical equipment (inc. electronic equipment), Industrial equipment / machinery, [OTHER]: gifts* – was decided to assume the other selections sufficiently covered *Gifts*
- *Basic metal products, Fabricated metal products, Transport equipment (inc. motor vehicles), [OTHER]: Composites* – was decided to assume *Basic metal products* sufficiently covered *Composites*
- *[OTHER]: Marine Electrical Design* was replaced with *Appliances / electrical equipment (inc. electronic equipment)*
- *[OTHER]: service industry* was assumed to be included in *Communications* and *Electricity/gas* which the person also selected

Responses to Section III Q19 Question on Key Responsibilities

Decisions on How to Record Individual Responses

- *Management, Project study/analysis, [OTHER]: Strategy development* – *Other* was assumed to be covered by *Project study/analysis*
- *Project study/analysis, [OTHER]: Policy consideration and advice* – *Other* was considered to be covered by *Project study/analysis*
- *Management, [OTHER]: Consulting* – *Other* was replaced with *Project study/analysis*
- *[OTHER]: data entry* – This person selected no other options for this question. The person had 6 years of experience, all full time, is called a grad engineer, discipline is control. Has to learn new skills monthly. Only positive organization factor is PD (so is not challenged or valued). However, the person has selected more tasks than just data entry. Looking at the tasks, it looks like the person could be e.g. writing ladder diagrams – which could be *R&D (inc. product design/development)* - This selection does not seem consistent with the engineer feeling unchallenged. However, ladder diagrams etc are not challenging. If this person was working for the client and doing the same thing, then the work would be called *Production/quality/maintenance*.
- *Other: Risk management advice* was replaced with *Project study/analysis*
- *Production/quality/maintenance, Teaching/training, [OTHER]: Service Quality* – *Service Quality* was considered to be included in *Production/quality/maintenance*
- *Management, [OTHER]: design* – *design* replaced with *R&D (inc. product design/development)*
- *Other: Commissioning* was replaced with *Construction supervision*
- *Construction supervision, Management, [OTHER]: consultation* – *consultation* was replaced with *Project study/analysis*
- Person selected no key responsibilities. Position title is Business Planner – was decided to record *Project study/analysis*
- *[OTHER]: Design Standards*. This person works for *water/sewerage/drainage government organisation*. Could be *Production/quality/maintenance* or could be *Project study / analysis*, depending whether the person meant that he designed standards or he used design standards. *Project study / analysis* would be fine for either case, so recorded *Project study / analysis*
- *Management, [OTHER]: Briefing/Advising* – was replaced *Briefing/advising* with *Project study / analysis*
- *Management, [OTHER]: Advising Minister* – was replaced *Advising Minister* with *Project study / analysis*

- *Management, Project study/analysis*, [OTHER]: *project management* – *Project management* was considered to be included in *Management*
- [OTHER]: *Policy and investment planning* – was replaced with *Project study / analysis*
- [OTHER]: *Software Design & development* – was replaced with *R&D (inc. product design/development)*
- *Design of equipment/processes (not product design), Sales/marketing*, [OTHER]: *structural design, managing projects & junior staff* – replaced *structural design* with *R&D (inc. product design/development)* and *managing projects and junior staff* with *Management*
- [OTHER]: *Software Design* was replaced with *R&D (inc. product design/development)*
- [OTHER]: *IT Systems Design & Administration* was replaced with *R&D (inc. product design/development)*
- *Management*, [OTHER]: *Environmental Problem Solving* - replaced *Other* with *Project study / analysis*
- [OTHER]: *Design management* was replaced with *Management* and *R&D*
- *Production/quality/maintenance, Project study/analysis*, [OTHER]: *Evaluation/New Product Transfer/Testing* – replaced *other* with *R&D (inc. product design/development)*
- *Management*, [OTHER]: *Traffic Concept Planning, Land Use Management* – *Other* was replaced with *Project study / analysis*
- [OTHER]: *Hands on Trouble Shooting* – was replaced with *Production/quality/maintenance*
- *Management, Teaching/training*, [OTHER]: *Masters degree development - systems integration* – *Other* was considered to be covered by remaining two selected options
- *Construction supervision, Management, Project study/analysis*, [OTHER]: *Infrastructure design* – *Other* was replaced with *R&D (inc. product design/development)*
- No response selected. Position title *specialist engineer* – *structural integrity* – organization code *Pilbara* – *Project study / analysis* and *Design of equip/processes* and *Production / quality / maintenance* were recorded
- [OTHER]: *Report System design & operations* was replaced with *Design of equip/processes* and *Production/quality/maintenance*
- [OTHER]: *Planning & development* was replaced with *R&D (inc. product design/development)*
- [OTHER]: *Design Standards and Design Management* was replaced with *Project study / analysis* and *Management* and *R&D (inc. product design/development)*
- *Construction supervision, Management*, [OTHER]: *estimating* – *estimating* was replaced with *Project study/analysis*
- *Management*, [OTHER]: *IP advice* – *Other* replaced with *Project study / analysis*
- [OTHER]: *Resource exploration* was replaced with *Project study / analysis*
- *Management, Sales/marketing, Teaching/training*, [OTHER]: *Technical Design* – *Other* was replaced by *R&D (inc. product design/development)*
- *Construction supervision, Management*, [OTHER]: *Project Management* – *Other* was considered to be included in *Management*
- *Design of equipment/processes (not product design), Project study/analysis*, [OTHER]: *Software Development, Functional Safety Management* – *Software development* was replaced with *R&D (inc. product design/development)*, *Functional Safety Management* was replaced with *Management* and also considered to be included in *Design of equipment/processes*

- *[OTHER]: Facilitation/Specialist Technical* was replaced with *Design of equip/processes, Management, R&D (inc. product design/development)* (*Management* selection was advised by the tasks the person selected. The engineer reported his work to be *partly technical*.)
- *Specialist writer* – replaced with *Project study / analyst*
- *Provision of legal services and advice* was considered to be included in *Project study / analysis* which was also selected

Comment about this question: When attempts were made to replace *Other* responses with an existing option, *Design of equipment/processes (not product design)* has been difficult to differentiate from *R&D (inc. product design/development)*. The difference is unclear when the product is part of the equipment/processes for the client e.g. with design of control systems or software development. These were recorded as *R&D (inc. product design/development)* but respondents might have found them ambiguous.

Responses to Section II Q10 Question on Completed Qualifications

Coding Decisions

Decided to separate into 2 variables: highest technical qualification and highest non-technical qualification.

Is Masters higher than Honours? Yes

Is graduate diploma higher than honours? Decided to ignore technical graduate diplomas as they would not add much to the BE

Decided to include non-technical graduate diplomas as they would add a new dimension to the BE

Only had 3 with BE(Hons3), so combined with BE(Hons2)

Codes

Highest Technical qualification

1 BE P

2 BE H2/3

3 BE H1

4 Masters in Tech area

5 PhD in technical area

Highest Non-technical qualification (including Commerce)

1 Non-technical graduate diploma

2 BCommerce (joint degree)

3 MBA

Decisions on How to Code Individual Responses

Bachelor of Engineering (Hons2A/2B/2), [OTHER]: CEng MICE, PMP

Did not know what *PMP* was.

BSc. Mech Eng (Hons) Imperial College London

A 3 year degree can be honours in England, so was not sure what to call this. Chose *H2*

[OTHER]: Dip Ed (Sec.) recorded as 1: Grad Dip for non-tech

1,[OTHER]: postgrad metallurgy, postgrad management
assumed this meant the person was still a student in these 2 things, therefore ignored these comments

Bachelor of Engineering (Pass only),Masters in engineering or technical field,[OTHER]: Doctoral candidate – recorded as level 4 technical qualification

Bachelor of Engineering (Hons2A/2B/2),[OTHER]: Part of MBA
Recorded as level 1 for non-technical qualification

[OTHER]: MIR

Did not know what MIR was. (member of something or masters in something?)
Guessed Masters in non-tech area. Made no difference because engineer had an MBA.

Final Modification to Coding for Qualifications

There were only 5, 3 and 18 engineers with Grad Dip, B Commerce and MBA respectively. Therefore, these were combined for analysis. The non-technical qualification variable became: No non-technical qualification 0 / non-technical qualification 1.

Appendix XVI. Paper Questionnaire for Survey 2

The size of the questionnaire has been reduced to fit the questionnaire into the thesis pages. The questionnaire was printed on three double-sided yellow A4 pages.

Survey on Required Competencies of Established Engineers

Please return completed questionnaire by Friday 21 September 2007

To complete this questionnaire you must be a senior engineer with over 20 years of experience, and you must be experienced in managing, supervising or directing engineering teams that have included engineering graduates with 5 to 20 years of experience since graduating from their degrees of 4 years or more.

Part I. Demographic Questions

1. Do you have any <u>non-technical</u> qualifications (e.g. <i>MBA, BComm</i>)?	☐ No ☐ Yes
2. What is your highest level of <u>technical</u> qualification?	☐ No technical qualification ☐ Certificate or diploma ☐ Bachelor ☐ Honours ☐ Masters or doctorate
3. How many years of engineering experience do you have?	_____
4. In which country did you complete your secondary education?	_____
5. In which country were you awarded your engineering qualification? (If you do not have an engineering qualification skip to Q7)	_____
6. Do you have an undergraduate engineering qualification awarded by The University of Western Australia?	☐ No ☐ Yes

7. Which of the following is the main engineering discipline area in which you are experienced? (Tick one)	☐ Civil / Structural / Environmental / Geotechnical / Mining ☐ Computer Systems / Electrical / Electronic / Communications / Software / IT ☐ Mechanical/ Aeronautical/ Materials/ Mechatronics/ Metallurgical/ Naval architecture/ Chemical
8. Gender?	☐ Female ☐ Male
9. In which sector is most of your experience? (Tick one)	☐ Private sector ☐ Government sector / government business enterprise ☐ University / tertiary sector
10. Is the main organization in which you are experienced a consulting engineering firm?	☐ No ☐ Yes
11. How many <u>employees</u> are employed by the main organization in which you are experienced?	☐ 1 to 50 ☐ 51 to 500 ☐ Over 500
12. How many <u>professional engineers</u> are employed by the main organization in which you are experienced?	☐ 1 to 10 ☐ 11 to 100 ☐ 101 to 500 ☐ Over 500
13. In which country have you mainly worked?	☐ Australia ☐ Other _____-> Jump to Q15
14. In which Australian state or territory have you mainly worked?	_____

15. In which industries have you mainly been engaged?
(Tick all that apply)

Non-manufacturing Industries

- ☐ Consulting/technical services
- ☐ Construction/contract/maintenance
- ☐ Mining/quarrying
- ☐ Oil/gas exploration/production
- ☐ Electricity/gas supply
- ☐ Water/sewerage/drainage
- ☐ Communications (*inc. Telstra*)
- ☐ Defence
- ☐ Public administration
(*Federal/State/Local*)
- ☐ Transport/storage
- ☐ Education

Manufacturing Industries

- ☐ Food/beverage/tobacco
- ☐ Wood/furniture / paper products
- ☐ Chemical/petroleum products
- ☐ Non-metallic mineral products
- ☐ Basic metal products
- ☐ Steel production
- ☐ Fabricated metal products
- ☐ Transport equipment (*inc. motor vehicles*)
- ☐ Photographic/scientific equipment
- ☐ Appliances / electrical equipment (*inc. electronic equipment*)
- ☐ Industrial equipment / machinery
- ☐ Other

16. Please think of a specific typical job performed by a graduate engineer with 5 to 20 years of experience, in the main organization in which you are experienced. Please refer to that job for the remainder of the survey.
What are the key responsibilities of the typical job?
(Tick all that apply)

- ☐ Construction supervision
- ☐ Design of equipment/processes
(*not product design*)
- ☐ Management
- ☐ Production/quality/maintenance
- ☐ Project study/analysis
- ☐ Research/development (*inc. product design/development*)
- ☐ Sales/marketing
- ☐ Teaching/training

Questions 7, 9-12, 15-16 adapted from APESMA/EA Spring 2005 Professional Engineer Remuneration Survey

Part II. Competency Inventory

In the previous question you referred to a specific typical job performed by a graduate engineer with 5 to 20 years of experience, in the main organization in which you are experienced.

How important is each of the following for an engineer to do the typical job well?

(Tick the best response for each competency)

Group effectiveness/teamwork

1=not needed; 5=critical

17. Interacting with people from diverse cultures / backgrounds	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
18. Interacting with people in diverse disciplines/professions/trades	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
19. Mentoring/coaching co-workers	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
20. Working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Communication

1=not needed; 5=critical

21. Communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
22. Managing his/her own communications (e.g. keeping up to date and complete, following up)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
23. Negotiating / asserting/defending approaches/needs	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
24. Presenting clearly and engagingly (e.g. speaking, lecturing)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
25. Speaking and writing fluent English	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
26. Using effective graphical communication (e.g. reading drawings)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
27. Using effective verbal communication (e.g. giving instructions, asking for information, listening)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
28. Working effectively in a second country	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Creative thinking / problem solving

1=not needed; 5=critical

29. Applying mathematics, science or technical engineering theory or working from first principles	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
30. Appreciating aesthetic features of design	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
31. Being familiar with complete lifecycle of projects/programs/products	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
32. Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in his/her discipline of engineering (e.g. ability to recognise unrealistic results)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
33. Evaluating / advocating for / improving maintainability	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
34. Evaluating / advocating for / improving manufacturability	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
35. Evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
36. Evaluating reliability / potential failures	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Referring to the same typical job, how important is each of the following for an engineer to do the typical job well?

	<i>1=not needed; 5=critical</i>				
37. Evaluating the impact of engineering solutions in the social/cultural/political contexts (<i>local/global</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
38. Generalising/abstracting concepts	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
39. Modeling/simulating/prototyping and recognising the limitations involved	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
40. Solving problems (<i>e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
41. Sourcing/understanding/evaluating information	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
42. Thinking critically to identify potential possibilities for improvements	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
43. Thinking laterally / using creativity/initiative/ingenuity	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
44. Trying new approaches/technology / capitalising on change / initiating/driving change	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
45. Using 'simultaneous engineering design and development' / 'integrated product and process design' / 'collaborative engineering'	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
46. Using 3 dimensional spatial perception or visualisation (<i>e.g. visualizing various perspectives</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
47. Using a systems approach	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
48. Using design methodology (<i>e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
49. Using research / experimentation techniques / scientific method	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Organizational effectiveness / leadership

	<i>1=not needed; 5=critical</i>				
50. Actively promoting diversity within his/her organization (<i>e.g. culture, religion</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
51. Applying familiarity with risk/liability/legislation/standards/codes / IP issues	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
52. Applying familiarity with the different functions in his/her organization and how these interrelate	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
53. Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
54. Chairing / participating constructively in meetings (<i>e.g. team meetings / forums /workshops / focus groups / interviews</i>)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
55. Coordinating the work of others	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
56. Engaging in entrepreneurship / innovation / identifying and commercialising opportunities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
57. Evaluating marketing issues / applying a customer focus	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
58. Evaluating / advocating for / improving health and safety issues	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
59. Focusing on his/her organization's needs	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Referring to the same typical job as before, how important is each of the following for an engineer to do the typical job well?

	<i>1=not needed; 5=critical</i>				
60. Leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
61. Making decisions within time and knowledge constraints	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
62. Managing (e.g projects/programs/contracts/people /strategic planning/performance/change)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
63. Networking (i.e. building/maintaining personal/organizational networks)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
64. Supervising work/people	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
65. Taking considered risks	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
66. Understanding social and political dimensions of workplaces	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Self management / personal style / life-long learning

1=not needed; 5=critical

67. Being positive/enthusiastic/motivated	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
68. Engaging in active citizenship (e.g. being involved in the local / national or international community / engaging in public debates)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
69. Having an action orientation (e.g. avoiding delays, maintaining a sense of urgency)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
70. Keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
71. Managing information/documents	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
72. Managing personal and professional development (e.g self directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
73. Managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Work-related dispositions and attitudes

1=not needed; 5=critical

74. Acting within exemplary ethical standards	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
75. Being committed to doing his/her best	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
76. Being concerned for the welfare of others in his/her organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
77. Being concerned for the welfare of the local, national and global communities	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
78. Being loyal to his/her organization (e.g. representing it positively)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
79. Demonstrating honesty (e.g. admitting his or her mistakes, giving directors bad news)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5
80. Presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)	☐ 1	☐ 2	☐ 3	☐ 4	☐ 5

Please return questionnaire to **CEG Project M017** The Faculty of Engineering Computing and Mathematics,
The University of Western Australia, 35 Stirling Highway, Crawley WA 6009

Appendix XVII.

Letter of Invitation to Participate in Survey 2

Office of the Dean (M017)

Faculty of Engineering, Computing and Mathematics
The University of Western Australia
35 Stirling Highway, Crawley, WA 6009
Phone: +61 8 6488 3704
Fax: +61 8 6488 1026
CRICOS No: 00126G
Email: dean@ecm.uwa.edu.au
Professor Mark B Bush

9 August 2007

<Title><Name>
<Suburb><State><Postcode>

Dear < > ,

Invitation to Help Improve the Alignment of Engineering Education with the Expectations of Your Industry

The Faculty of Engineering, Computing and Mathematics at The University of Western Australia is now conducting Phase 2 of a major project to develop methods for surveying employers to produce a profile of engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. A fundamental component of the project involves identifying the key competencies required of engineering graduates.

Phase 1 of the Project surveyed engineers with 5 to 20 years of experience to identify the competencies that they view as important for their work. The Phase 2 survey is targeted at senior people responsible for managing these engineers. Its purpose is to validate the outcomes of the first survey.

I would like to invite you to complete the Phase 2 questionnaire. Participants must be senior engineers with more than 20 years of experience. They must be experienced in managing, supervising or directing engineering teams that have included engineering graduates with 5 to 20 years of experience since graduating from their degrees of 4 years or more. We need responses from both industry and higher education.

Participation takes less than 15 minutes. The questionnaire can be completed on the enclosed paper questionnaire or online at <http://www.ceg.ecm.uwa.edu.au>

The study is being conducted as a Ph.D. project by Ms. Sally Male, supervised by Dr. Elaine Chapman, and me.

The participation of senior engineers will be essential to the success of this project. We will be most grateful if you can spare some time to complete the questionnaire. Participants are offered a survey report and acknowledgment in the thesis.

Thank you for considering this request.

Yours sincerely,

Dean

Appendix XVIII. Information Sheet for Survey 2

(Paper Version)

THE UNIVERSITY OF
WESTERN AUSTRALIA

Survey on Required Competencies of Established Engineers

Information Page Provided to Participants to Ensure Ethical Recruitment of Volunteers

This survey of senior engineers is Phase 2 of the Competencies of Engineering Graduates (CEG) Project. Sally Male (PhD candidate, UWA) is conducting this research under the supervision of Professor Mark Bush (Dean, Faculty of Engineering, Computing and Mathematics), and Dr Elaine Chapman (Associate Dean - Research, Faculty of Education). The ultimate goal of the project is to develop methods for surveying employers to produce a profile of engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations.

We require the expert opinions of engineers to achieve success in this very important project. Initially the CEG Project surveyed engineers with 5 to 20 years of experience, to identify the competencies that they view as important for their work. This second survey in the Project is targeted at senior people responsible for managing these engineers. Its purpose is to validate the outcomes of the first survey.

Who is Invited to Complete the Questionnaire?

Participants must be senior engineers with more than 20 years of experience. They must be experienced in managing, supervising, or directing engineering teams that have included engineering graduates with 5 to 20 years of experience since graduating from their degrees of 4 years or more.

What is Involved for Volunteers Completing the Questionnaire?

The questionnaire may be completed online or on paper. It takes less than 15 minutes to complete. Your responses will remain anonymous. The questionnaire will ask some general questions about you and your background, and about the types of competencies you consider most important for established engineers.

Acknowledgement

People who complete the questionnaire are invited to receive a report on the survey results and to be acknowledged in the PhD thesis. Names and email addresses will be stored separately from the responses and will not be matched at any time.

Consent to Participate

Completion of the questionnaire is considered evidence of consent to participate in the study. You are free to withdraw from the study at any time by not completing the questionnaire.

Questions about the Survey

Questions are welcome. Please contact one of the researchers either by e-mail or by telephone with any questions you have about this survey or about the CEG project (contact details below).

Complaints

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively, to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703).

Contact Details for the Researchers

Professor Mark Bush, Dean, Faculty of Engineering, Computing and Mathematics, M017, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009; Telephone: 6488 3704; Fax: 6488 1026; Email: mark.bush@uwa.edu.au

Dr Elaine Chapman, Associate Dean - Research, Faculty of Education, M428, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009; Telephone: 6488 2384; Fax: 6488 1052; Email: elaine.chapman@uwa.edu.au

Ms Sally Male, PhD Student, M017, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009; Fax: 6488 1052; Email: males01@student.uwa.edu.au.

Website

The questionnaire is available online at <http://www.ceg.ecm.uwa.edu.au/seniorengsurvey>

**Appendix XIX. Consent Form for Survey 2 (Paper
Version)**

THE UNIVERSITY OF
WESTERN AUSTRALIA

Survey on Required Competencies of Established Engineers

Offer for Participants

In appreciation of your support participants in the Survey on Required Competencies of Established Engineers are invited to receive a report on the survey results and to be acknowledged in the PhD Thesis.

Participants may accept this offer by visiting <http://www.ceg.ecm.uwa.edu.au/thankyou>

OR

by returning this form by post.

I wish to receive a report on the survey results at

E-mail Address: _____

I wish to be acknowledged in the PhD Thesis as

Surname and Initials: _____

PLEASE RETURN TO
CEG Project, M017
The Faculty of Engineering, Computing and Mathematics
The University of Western Australia,
35 Stirling Highway, Crawley, WA 6009

Appendix XX. Competency Deficiencies in Engineering Graduates

This appendix is adapted from a paper published in the *Australasian Journal of Engineering Education* (Male *et al.* 2010a) and written by the PhD candidate.

1. Introduction

Engineering education in Australia continues to change (2006b). Course structures, the breadth of curricula, teaching methods, and learning environments are evolving. The University of Melbourne has, and The University of Western Australia (UWA) soon will, replace four-year bachelor of engineering courses, with three-year bachelor courses followed by two-year masters in engineering. Problem-based and project-based learning, teamwork and peer assessment, are becoming increasingly popular. As required for program accreditation, non-technical components including ethics, life-long learning, teamwork, and communication skills, are now part of engineering curricula. This study is motivated by the view that engineers' perceptions of deficiencies of past and recent graduates should be considered when engineering education is changed. The study asks:

Are current changes to engineering education consistent with competency deficiencies in engineering graduates perceived by engineers?

This study is part of a larger study on generic competencies required by engineers graduating in Australia. This study uses qualitative questions from Survey 1 from which quantitative sections are reported elsewhere (Male *et al.* 2009a, Male *et al.* under review).

International studies have identified competency deficiencies in engineering graduates, as perceived by various stakeholders. Competency deficiencies in graduates have also been referred to as “skills gaps”, referring to the difference between the level

of competence required for employment or alternatively the importance of competencies for employment, and the level of competence of graduates. Large-sample surveys have measured competency deficiencies in engineering graduates, based on perceptions of engineers or employers.

In a European and USA survey, 1372 engineers with bachelor, master or diploma degrees rated engineering competencies and general professional competencies on importance and graduate performance (Bodmer *et al.* 2002). The largest indicated gaps were in communication skills, leadership skills and social skills.

In a UK survey, 256 employers of engineering graduates rated their satisfaction with skills which had been identified as important in an earlier phase of the study (Spinks *et al.* 2006). There was small yet statistically significant dissatisfaction with practical application, and business skills, and to a lesser extent, technical breadth. Interviews supported the concern about practical application.

In an international survey of chemical engineers from 63 countries, during their first five years of employment, participants ranked skills and abilities with respect to the quality of their education, and also the relevance to their work (WCEC 2004). If the average rank for work was lower than that for education, the skill or ability was identified as being in deficit. On average across all 1091 engineers with bachelor degrees, the skill or ability rated as having the highest identified deficit was business approach. Ratings for quality management methods, project management methods, management skills, effective communication and leadership also indicated relatively high deficits.

As demonstrated by the variation across countries that can arise in survey results (for example, WCEC 2004), rather than making the assumption that findings from overseas generalise to Australia, it is prudent to also obtain Australian data.

Communication is the competency that features most frequently as a deficiency in Australian surveys. In a survey by Bons and McLay (2003), among 98 participants, 45 RMIT engineering graduates from 1989 to 1997 with at least five years' experience, ranked 27 graduate attributes on importance and also preparation. The graduates' responses indicated the largest gaps for accountability, teamwork, communication, interpersonal skills and *skills to advocate and influence*. In a survey by Ashman *et al.* (2008), among other participants, 40 fourth year undergraduate chemical engineering students, and six managers, rated graduate attributes on importance and competence. Mean importance and competence ratings for each sample group were compared. Managers' and undergraduate students' ratings indicated a deficiency in communication, and managers' ratings indicated a slight deficiency in graduates' business skills. Nair *et al.* (2009) investigated gaps between education and workplace needs of engineers, using a survey of 109 engineering-related employers. The largest identified competency gaps were in the areas of communication, problem-solving, time-management, teamwork, application of knowledge in the workplace, ability to cope with stress, and capacity to learn.

Emotional intelligence was judged by participants' ratings to have the largest gap between importance and performance in an Australian survey conducted by Scott and Yates (2002). Survey participants were 20 students and 10 supervisors. Items in the survey were developed using interviews.

A business approach was found to be the skill with the highest deficit based on responses from 70 chemical engineers from Australia with a highest qualification at the bachelor level, in the international survey of chemical engineers cited above. Ratings from the engineers from Australia indicated higher deficits than the deficits indicated by average ratings from bachelor participants across all countries (WCEC 2004). However, the skills and abilities with the highest deficits were consistent with the international

results. A business approach, as the skill which was rated with the highest deficit, was followed by quality management methods, project management methods, management skills, effective communication and leadership.

Additionally, reviews of engineering education in Australia have invited industry views. At the time when many of the eldest participants in the current study were undergraduate students, the Williams review received comments noting a lack of realistic problem-solving in the curriculum and poor written and oral communication skills of graduates (Williams 1988a). Based on engineering courses in 1986, 514 engineering employers rated preferred course content (Williams 1988b). Among six listed content areas, those for which the highest numbers of respondents would have preferred more content were computing (63% of respondents), engineering professional skills (49%) and *humanities and other professional elements* (38%). Mean ratings of perceived adequacy of course emphasis identified perceived inadequacy in *involvement with non-engineering disciplines in project work, industrial relations / management of people, and the management of costs and resources*. The report on the impact of the Williams review noted increased emphasis on the “human element in technology” and communications skills (Caldwell *et al.* 1994, p.9).

For the Australian review of engineering education *Changing the Culture: Engineering Education into the Future* (Johnson 1996b), 51 structured interviews of engineers and engineering employers, and a large qualitative survey ($N = 300$), were conducted. Identified graduate competency deficiencies were in interpersonal skills, communication skills, understanding of the broad context of decisions, creativity, innovation, design and problem-solving skills, and teamwork. The requirement for diverse graduate competency profiles was also raised.

During the most recent review of engineering education in Australia (Johnston *et al.* 2008), engineers’ views on engineering education were collected from focus group

discussions, consultations, and submissions. The report refers to industry comments on poor written communication skills, fundamental science and engineering knowledge, practical experience, familiarity with industry standards and codes, financial constraints, and engineering-specific project management skills. However, graduates' oral communication skills, teamwork, and use of software tools were perceived to have improved, which suggests a swing in industry's opinion since the Williams review.

This study contributes Australian data on competency deficiencies of engineering graduates, collected using a research method with a unique combination of features, making it different from and complementary to previous methods.

2. Method

This study used open questions at the beginning of a questionnaire in a survey of 300 participants (Survey 1). The method is unique in its combination of three unusual features. First, it asked open questions independently of a large sample. Previously in Australia, only the Johnson review (1996b) had used a qualitative survey to study competency deficiencies. Second, the survey questions asked directly about competency deficiencies, rather than calculating them by comparing ratings of competencies on two other dimensions. Third, participants were asked about both recent and less recent graduates, thereby revealing perceived changes in graduate competencies. These features of this study's method are described below.

The previous studies discussed above used surveys or mixed methods, combining interviews and/or focus groups involving relatively small samples; and surveys with larger samples. Competency deficiencies have been identified using ratings or rankings of items in a list. The qualitative components of previous studies have benefited from depth of investigation, and the ability to ask open questions and thereby collect new ideas. The surveys have benefited from larger samples. However, with the exception of the Johnson review, open questions, collecting qualitative data, have been avoided in

large-sample surveys, because the analysis can be time-consuming. Consequently, generalisable results have been collected from the large-sample surveys but fresh ideas have been gleaned only from small samples. In this study, brief responses were requested and therefore depth of understanding was not explored. However, this was traded for the opportunity to pragmatically collect and analyse, from a large sample, responses which were not influenced by previous questions or guided by a finite number of response options. The advantage of a large number of participants is improved generalisability of results.

This study also differed from previous studies, except the reviews, by taking an approach that directly collected perceptions of competency deficiencies, rather than indirectly identifying competency gaps among a list of competencies by using mean ratings of importance and competence. Using the open questions at the beginning of the questionnaire, it was possible to collect, from a large number of engineers, the competency deficiencies that they perceived as important.

Finally, this study asked one sample of participants about both the participants' graduate competencies, and recent graduate competencies. This provided the opportunity to reveal perceived progress in engineering education.

3. Survey Design

Survey 1 was implemented online (Male *et al.* 2009a). Participants were engineers with five to twenty years' experience since completing an engineering degree of at least four years. These engineers were expected to have an understanding of the competency requirements of engineers, and not yet to have mostly moved into largely different stages of their careers. Letters invited participation from 2542 graduates who completed bachelor of engineering degrees at UWA from 1985 to 2001. Calls for participants were also distributed through professional engineering associations, and members of

industry advisory groups within the engineering faculty. Three hundred usable responses were received.

The first two questions in the questionnaire, including their online page heading were:

Section I of V: Graduate Attributes (2 brief questions)

1. Is there a skill, attribute or area of knowledge that you would have liked to gain from your undergraduate engineering studies and did not?
If “Yes”, please specify
2. Is there a skill, attribute or area of knowledge that you have observed to be lacking in engineering graduates who have completed their degrees within the last 3 years?
If “Yes”, please specify

These questions therefore asked the engineers to reflect on competency deficiencies experienced as graduates, and then competency deficiencies perceived in recent graduates. It was expected that differences between the two questions would be affected by the differences between self-assessment and assessment of others, changes in the work of engineering graduates, and changes in engineering education between that experienced by participants, and that experienced by recent graduates.

Sensitive, threatening and leading questions were avoided. As recommended by Foddy (1993), the two questions were designed to be clear and simple, with abstract terms avoided where possible. However, Foddy also emphasises the importance of clearly defining the nature of the information required and ensuring that the meaning of individual words is not ambiguous. Multiple terms referring to competencies and attributes have been used with different meanings, even within the same context (OECD 2002, Barrie 2006). The use of the three terms, “skill”, “attribute” or “area of knowledge”, in the questions, was designed to avoid confusion and to avoid concern among participants about details between different related terminology and concepts.

To collect fresh responses, the questions were open-response, as are more often recommended for interviews than surveys. The questions allowed yes or no responses. Such questions allow participants to answer briefly and are therefore not recommended for interviews (Merriam 2009). However, the response rate for surveys can be damaged by forcing text responses. The selected wording also ensured that participants were not encouraged to identify a competency gap if they did not perceive one.

The second question narrowed the focus to engineering graduates “who have completed their degrees within the last three years”. Although this increased the length of the question, it was stipulated to narrow the focus of the question sufficiently to collect the required responses and allow responses to be compared, as Fodder reminds is essential.

Testing is recommended to improve reliability of open-response questions (Silverman 2010). Reliable understanding of the questions was evident in responses received from seven engineers, with appropriate experience, who tested the online questionnaire.

4. Results and Analysis

4.1. Demographics

Respondents’ demographic data demonstrate a diverse sample. Participants completed their first engineering degrees before 2002 (Figure 34). Additional demographic data are presented in Chapter 6.

Figure 34. Years in which Survey 1 participants completed their first engineering degrees

4.2. Analysis of Responses to the Open Questions

4.2.1. Units of Data

Initially, units of data were identified in the responses to the two questions. These were the shortest strings of text that made sense and stood alone without leaving remaining adjacent text that alone was meaningless. These units were not removed from the question responses. Instead, units of data were colour-coded and the responses were kept intact to maintain the possibility of gleaning an improved understanding of the meaning intended by a respondent.

4.2.2. Identification of Themes

A list of conceptual themes was developed iteratively, to group units of data that indicated similar competency deficiencies. The themes all evolved from repeated concepts in the data, and most were named after words in the data. However, the purpose of the study influenced the dimensions used to identify the themes, and awareness of current and past changes to engineering education in Australia and elsewhere also provided insight. The purpose of identifying competency deficiencies is to assist continuous improvement of engineering education across all disciplines.

Therefore, themes were identified to be generic across disciplines of engineering, and

the themes were selected to group competency deficiencies that might be addressed simultaneously by the same, or similar, improvements to engineering education.

Awareness of past and current changes to engineering education in Australia, and innovations in engineering education elsewhere provided insight for identifying themes that might be addressed simultaneously.

The list of themes was designed to satisfy the criteria specified by Merriam, being “responsive to the purpose of the research”, “sensitive to the data”, covering all relevant data, “mutually exclusive”, and “at the same conceptual level” (Merriam 2009, pp. 185-186). A list of the themes, with examples, was developed.

At an early stage *design* was named a theme. However, the criterion that themes be mutually exclusive, meaning that any unit of data should belong to only one theme, caused a problem. The following examples belonged to the practical theme and also the design theme: “practical electrical engineering design skills”, “practical hardware design”, “practical pit design”, “practical structural design examples”, and “practical design work”. Therefore, the design theme was made part of the practical theme.

A borderline decision was required for “water treatment technologies” and “traffic engineering”. These were originally coded as theory, because they were considered to be holes in theory. They were moved to the practical theme after a decision that they were applications of theory. In contrast, “hydrogeology” and “radio communications design” were coded as theory because they were considered to be more theoretical items.

Twelve themes were identified. Any one item alone was not considered a theme. The health safety and environment (HSE) theme was not represented in the responses to the first question because only one unit of analysis, “electrical safety” was related to it, and this also fitted the practical theme. The risk theme was not present in responses to the second question.

Although the first level of analysis was designed to be relevant to all disciplines of engineering, a second level of analysis reduced the practical theme into general competencies and those raised by graduates from each of three broad disciplines. This breakdown was clear in the data.

Responses from UWA and other graduates were separated to reveal any bias due to the high portion of responses from UWA graduates.

4.2.3. Data Display

Responses to each question were displayed separately. The units of analysis within each person's response to each open question were colour-coded by theme. For example, in Response 1 below, "Australian Standards" was coloured red to indicate the business theme and "PLC programming" was coloured blue to indicate the practical theme.

Every question response was then coded with a value for each theme (0 = *response does not include a unit of analysis fitting the theme*; 1 = *response does include a unit of analysis fitting the theme*). Response 1 was coded 1 for each of the business and practical themes, and 0 for all other themes. The number of people whose responses included a particular theme was the sum of the values for that theme.

Response 1. Australian Standards, PLC programming
(response to Q1 from Electronic/Communications engineer who completed engineering at UWA in 1989)

4.3. Responses to Question 1. Is there a skill, attribute or area of knowledge that you would have liked to gain from your undergraduate engineering studies and did not?

Responses under the theme of engineering business were received from engineers spanning the complete range of graduation years in the sample (1984 to 2001), across

all disciplines, and even including graduates who combined their engineering degrees with economics or commerce degrees. Responses relating to practical awareness included those related to familiarity with equipment and sites, and discipline-specific responses related to applications relevant to employment industries.

Understanding of engineering business and practical awareness featured most frequently (Figure 35 and Figure 36). Responses were collated in two groups: those from engineers who completed their degrees before 1996 and those who completed their degrees in or after 1996. These ranges were selected to place sufficient responses for comparison in each group, and also to reveal any significant change following the major Australian review of engineering education published in 1996 (Johnson 1996a). The most apparent difference, between responses from engineers who completed their degrees before 1996 and the more recent graduates, is that a lower percentage of the engineers who completed their degrees in or since 1996 identified competencies related to engineering business. Engineering management was added to many engineering curricula at UWA in 1989, following the Australian review of engineering education published in 1988 (Williams 1988b).

Figure 35. Themes among responses from *graduates of 1984-1995*, to Question 1 of Survey 1. Is there a skill, attribute or area of knowledge that you would have liked to gain from your undergraduate engineering studies and did not?

$(N_{UWA} = 131) (N_{Other} = 39)$

Figure 36. Themes among responses from *graduates of 1996-2001*, to Question 1 of Survey 1. Is there a skill, attribute or area of knowledge that you would have liked to gain from your undergraduate engineering studies and did not?

$(N_{UWA} = 86) (N_{Other} = 42)$

Themes Identified Among Responses to Question 1 of Survey 1

- No
- Yes, with no specification

- **Business:** “understanding of how engineers work”, including “contracts administration”, specifications, “contracting strategies”, “budgeting”, “estimation”, cost control, “finance”, “economics”, “commercial awareness”, project management, “construction management”, planning, scheduling, reporting, marketing, “relevant legislation”, Australian Standards
- **Practical:**
 - General: “practical design work”, “hands on practical experience”, “applying knowledge to practical work”, “more real world applications to theory”, “practical skills”, “practical hands on content”, “more practical experience on site”, “more practical exposure to work places & methods”, “more knowledge regarding the mining industry” (environmental graduate), “more case studies”
 - Civil: “more direct learning in civil design area”, “practical structural design examples”, “water treatment technologies”, “traffic engineering”, “transport/traffic management”, “more on road construction”, “practical pit design”, “grade control”
 - Electrical: instrumentation and industrial control/PLC programming/SCADA (mentioned by five electrical engineers), “electrical safety”, “practical electrical engineering design skills”, “more practical circuit design”, “lighting design”, “practical industrial control exposure”, “practical hardware design”, “better hardware design skills”, “practical structural design examples”
 - Mechanical: pumps (mentioned by nine mechanical engineering graduates), “piping knowledge (materials, fittings, calculations)”, “materials handling”, “applications of mechanical equipment in Australia”

- **Communication:** communication, presentation, report writing, interpersonal skills
- **Teams:** teamwork, leadership, negotiation, conflict resolution
- **Theory:** digital signal processing, image processing, cryptography, “more petrochemical knowledge”, numeric modelling, radio frequency propagation, radio communications design, computer-communications networking theory, hydrogeology, non-linear feedback control
- **Problem-solving:** problem-solving, systems engineering, “design skills – unstructured problem solving”
- **Risk management:** risk management, reliability, maintenance
- **Computing:** “More relevant software unit eg C rather than pascal, gopher”, databases, “more relevant computer skills”, “modern programming languages”, “better programming skills”, “programming”
- **Self-management / attitude:** “Understanding of attitude required & industry expectations” “reminded to use the knowledge of the people already doing it”, “admitting shortcomings”, “stress management”
- **Drawings:** reading drawings, using CAD
- **Health, safety and environment:** “HSE awareness”

Note: Quotation marks indicate direct quotation from a response. These have been included to allow readers to see nuances. Where no quotation marks are used, such as for the examples under the risk management theme, the term is usually an interpretation for similar units of data from multiple responses. Otherwise the term is a direct quotation but reveals no unique nuance.

4.4. Responses to the Second Question. Is there a skill, attribute or area of knowledge that you have observed to be lacking in engineering graduates who have completed their degrees within the last 3 years?

Responses to the second question were analysed using the themes developed from the first question. The theme, health, safety and environment (HSE) was additional.

Responses to the second question were expected to be more limited than responses to the first question. Not all of the survey participants had experience of recent graduates, and responding to the second question relied on generalisation more than the first question. This explains the higher number of *no* responses than for the first question.

Responses to the second question mainly included the same themes as for the first question, with practical engineering most frequently mentioned and engineering business third most frequently mentioned, although neither as frequently as in response to the first question. However, the second question raised a stronger emphasis than the first, on the themes of communication, problem-solving, and self-management and attitude (Figure 37). Samples of the comments under these themes are listed below.

Figure 37. Themes among responses to Question 2 of Survey 1. Is there a skill, attribute or area of knowledge that you have observed to be lacking in engineering graduates who have completed their degrees within the last 3 years?

($N_{UWA} = 217$) ($N_{Other} = 83$)

Themes Raised More Frequently in the Second Question than the First

- **Communication:** literacy, report and letter writing, “reasoned arguments”, “cohesive/persuasive argument”, listening skills, verbal communication skills, technical communication
- **Self-management / attitude:** “being grateful to have employment” (possibly a function of the employment market rather than the engineering education), “high standard of work is lacking”, “the drive to do the work”, “attitude has changed to work, less committed to work”, “willingness to exploit opportunities (e.g. site work)”, “community awareness”, “Recent graduates all want to be Project Managers”, “inability to work on multiple projects/jobs at the same time”, “time management”, “time/workload management”, “pragmatism”, “a sense of balance”, “lack of awareness of their limitations”
- **Problem-solving:** problem-solving skills, analytical skills, “logical thought process (e.g. scientific method)”, critical thinking, “question assumptions”, “systems (holistic) approach”, “look at total systems”, “systems engineering”, “trouble-

shooting”, “lateral thinking”, making decisions with limited information, “ability to apply their knowledge to engineering design”, “ability to work independently on problems”.

4.5. Validation

People would identify competencies as gaps, only if they are important. Although no other part of this study validated the competency gaps identified here, other components of the overarching project studied the importance of competencies to engineers’ work. In later questions in the survey, and in a second survey of senior engineers, 64 competencies were rated on importance.

Competencies related to communication, teamwork, problem-solving, self-management and practical engineering were rated highly (Male *et al.* 2009a). Senior engineers emphasised the importance of competencies similar to those categorized as engineering business in this study. In a focus group held to validate outcomes of the surveys, a sound understanding of fundamental science and mathematics was considered the first priority. These support the necessity of the competencies identified as gaps in this study.

5. Discussion

The engineers’ opinions collected in this survey provide insight for engineering educators. The outcome areas most frequently reported as desirable but missing from engineers’ undergraduate education were practical engineering and engineering business. Additionally, communication skills, self-management, attitude, problem-solving and teamwork were identified as competency deficiencies in engineering graduates.

One of the difficulties hindering the development of graduate attributes in engineering is the lack of a consistent definition of the attributes (Carew and Therese 2007). By

asking engineers about their own graduate experience, and due to the open-response format, this study collected specific examples of competencies that are named more generally in other studies. Consequently, the responses contribute to a better understanding of possible meanings of the competencies.

Practical engineering competency deficiencies included both familiarity with sites, tools and methods, and also applications in common industries in which the engineers were employed, for example instrumentation and control, pumps, road and pit construction. Design featured among responses in the practical engineering theme.

Engineering business competency deficiencies included awareness of how engineering is done, for example the relationships between contractors, consultants and their clients. Engineering business competency deficiencies also included skills in engineering work such as planning, specification, estimation, project management, cost control, risk management and maintenance management. These examples explain the comments received in the Johnston review, emphasising the need for engineering business competencies, rather than general business competencies only. This is a critical point which offers an opportunity for the engineering profession to enhance its identity. Engineering business competencies, in addition to the more readily recognised technical engineering competencies, distinguish professional engineers from other professionals.

All of the six highlighted competency deficiencies: practical engineering, engineering business competencies, communication skills, self-management and appropriate attitude, problem-solving, and teamwork, continue to be candidates for improvement in engineering curricula. Themes raised by the survey responses are consistent with previous studies. The three themes most prominent among the competency deficiencies identified in this study were practical engineering, business and communication. Practical engineering was highlighted as a competency deficiency in the UK study (Spinks *et al.* 2006) an Australian study (Nair *et al.* 2009) and Australian reviews.

Communication featured in many previous studies, and business competencies were highlighted by the UK study, the chemical engineering study (WCEC 2004), the Australian study by Ashman *et al.* (2008) and Australian reviews.

The introduction to this paper discussed some of the ways in which engineering education in Australia is evolving. Course structures, pedagogies, assessments and learning environments are changing. Are these changes aligned with the competency deficiencies identified by engineers in this study?

The results of this study suggest that engineering education has improved in at least two areas over the last two decades. Engineering business competencies and practical engineering competencies were identified in a smaller portion of the named competency deficiencies in responses to the second question, which asked about recent graduates, than in responses to the first question, which asked the engineers about their own experiences.

This could be due to improvements in engineering education. It could also be due to self-management, attitude, and problem-solving competencies being more recognisable in others than in self-assessment, and therefore eclipsing practical and business deficiencies in the second question. Comparison of the results of the previous studies that asked employers or managers to rate graduates, and those that asked engineering graduates to rate their own performance, is inconsistent with this second explanation for the apparent improvement in business and practical competencies of graduates.

Therefore, among the participants in this study, perceptions of graduates' competency deficiencies imply that the development of practical engineering and engineering business competencies in engineering graduates has improved since the participants graduated. This conclusion is consistent with broadening of engineering curricula to include business subjects during and since the mid 1980s, and engagement with engineers from industry which has been stipulated by criteria for accreditation of

engineering education programs (IEAust 1999a). Increased opportunities for project-based learning could have contributed to improvement in the development of practical engineering competencies.

This study supports continued broadening of engineering curricula, strategic collaboration with engineers in industry, and continued opportunities for students to develop practical engineering competencies. Engineering business competencies should be considered for inclusion in the graduate attributes stipulated by Engineers Australia (2005b) and the program outcomes stipulated by the Accreditation Board for Engineering and Technology (2008). Business competencies are explicitly listed under transferable skills stipulated in Europe (European Network for Accreditation of Engineering Education 2008).

Current developments in engineering education are aligned with competency deficiencies identified by engineers in this study. Communication, self-management and attitude, problem-solving and teamwork are now within engineering curricula and have been stipulated for program accreditation for many years (IEAust 1999a). Engineering educators have recognised that development of these competencies requires non-traditional pedagogies such as problem-based and project-based learning (Mills 2002, Shuman *et al.* 2005, Ferguson 2006a), and non-traditional learning environments in which to practise these (Norton *et al.* 2007).

Cultures within engineering and engineering faculties remain critical. Assessment methods and cultures must encourage learning in the required areas, and the best intentions can fail some students (Tonso 2007). Status for non-traditional competencies is required (Florman 1997). Education systems reinforce their cultures (Ihsen 2005). Part of many engineers' identities is affiliation with a culture giving technology higher status than business and people (Faulkner 2007). Therefore, it can be difficult for engineering academics to give communication and teamwork the necessary status to be

taught and learnt seriously within traditional engineering faculties, without cultural change. Further, the importance of research in universities has caused an increasing proportion of engineering academics to be without industry experience (Prados 1998). The Johnston (2008) review noted the growth of research-only staff in universities. This trend is likely to limit the status of practical engineering and engineering business within engineering faculties. Further cultural changes will be required to improve the success of current initiatives at addressing the competency deficiencies identified in this and previous studies.

6. Conclusions

This study used a different method from previous studies, to identify competency deficiencies among engineering graduates, as perceived by engineers. It confirms generalisation of large-scale international studies to the Australian context. Engineers identified competency deficiencies in engineering graduates. Dominant themes among the identified competency deficiencies were practical engineering, engineering business competencies, communication skills, self-management and appropriate attitude, problem-solving, and teamwork. Current changes to engineering education in Australia seek to address these deficiencies.

References

References are included in the References section of the thesis, before the appendices.

Appendix XXI. Survey Ratings of Importance for Each Competency

Teamwork

Written comm.

Managing comm.

Negotiation

Presenting

English

Graphical comm.

Verbal comm.

Working internat.

Theory

Aesthetics

Life-cycle

Practical

Maintainability

Manufacturability

Sustainability

Reliability

Social context

Generalisation

Modelling

Problem-solving

Sourcing info

Critical thinking

Creativity

Embracing change

Integrated design

3D skills

Systems

Design

Research

Promoting diversity

Liability

Cross-fn familiarity

Flexibility

Meeting skills

Coordinating

Entrepreneurship

Marketing

Safety

Focus

Leading

Decision-making

Managing

Networking

Supervising

Risk-taking

Workplace politics

Self-motivation

Citizenship

Action orientation

Keeping up to date

Info-management

Managing development

Self-management

Ethics

Commitment

Concern for others

Community

Loyalty

Figure 38. Frequency graphs for each competency, showing distributions of ratings of importance to doing an established engineering job well, in Survey 1 of 300 established engineers and Survey 2 of 250 senior engineers

Note:

1. Missing values (0.2% of values in Survey 1 and 0.3% of values in Survey 2) were replaced with medians of the ratings for the competency within each survey.
2. The graphs are in the order that the competencies were listed in the questionnaire because this allows inspection for influences of similar wording in consecutive questions.
3. The competencies are identified by their short names. The full names are listed in the same order in Table 1.

Appendix XXII. Normality of Competency Ratings

The competency importance ratings made by the engineers in Surveys 1 and 2 were transformed using LISREL to improve their normality without altering their means and standard deviations. Table 30 and Table 31 present the distribution statistics. The transformation reduced the kurtosis and skew values that previously had the highest magnitudes.

Table 30. Distribution statistics for Survey 1 of 300 established engineers

Competency importance ratings (Missing values replaced by medians) (1 = not needed; 5 = critical)							
Competency	Mean	SE of mean	SD	Skew (± 0.14)		Kurtosis (± 0.28)	
				Raw	Trans- formed	Raw	Trans- formed
Diversity skills	3.83	0.06	1.09	-0.67	-0.36	-0.30	-0.68
Interdisc. skills	4.42	0.05	0.80	-1.41	-0.88	1.70	-0.29
Mentoring	3.51	0.06	1.03	-0.30	-0.14	-0.53	-0.46
Teamwork	4.46	0.04	0.76	-1.75	-0.85	4.10	-0.28
Written comm.	4.54	0.04	0.67	-1.83	-0.93	5.13	-0.18
Managing comm.	4.49	0.04	0.61	-0.96	-0.69	0.77	-0.46
Negotiation	4.00	0.05	0.85	-0.63	-0.31	0.19	-0.47
Presenting	3.84	0.06	1.00	-0.67	-0.31	-0.01	-0.57
English	4.45	0.04	0.68	-1.10	-0.73	0.93	-0.45
Graphical comm.	4.16	0.05	0.85	-0.79	-0.48	0.12	-0.58
Verbal comm.	4.48	0.04	0.64	-1.08	-0.71	1.14	-0.44
Working internat.	2.23	0.08	1.33	0.71	0.51	-0.74	-0.94
Theory	3.30	0.07	1.21	-0.17	-0.13	-0.91	-0.70
Aesthetics	2.75	0.07	1.21	0.05	0.11	-1.04	-0.68
Life-cycle	3.67	0.06	1.06	-0.58	-0.23	-0.19	-0.57
Practical	4.28	0.05	0.82	-1.27	-0.58	2.04	-0.47
Maintainability	3.46	0.07	1.16	-0.65	-0.13	-0.30	-0.58
Manufacturability	2.61	0.07	1.29	0.25	0.21	-1.11	-0.84
Sustainability	3.11	0.07	1.26	-0.22	-0.02	-1.01	-0.73
Reliability	3.74	0.07	1.18	-0.84	-0.30	-0.08	-0.75
Social context	2.74	0.07	1.20	0.15	0.11	-0.91	-0.67
Generalisation	3.19	0.06	1.10	-0.25	-0.04	-0.46	-0.46
Modelling	3.11	0.07	1.26	-0.05	-0.05	-1.01	-0.75
Problem-solving	4.40	0.05	0.79	-1.24	-0.82	1.16	-0.38
Sourcing info	4.24	0.05	0.80	-1.15	-0.50	1.92	-0.47
Critical thinking	4.17	0.04	0.75	-0.76	-0.37	0.76	-0.38
Creativity	4.03	0.05	0.79	-0.43	-0.26	-0.35	-0.53
Embracing change	3.64	0.05	0.93	-0.31	-0.15	-0.28	-0.37
Integrated design	2.94	0.07	1.15	-0.10	0.03	-0.82	-0.54

3D skills	2.68	0.08	1.32	0.22	0.17	-1.14	-0.87
Systems	3.16	0.07	1.16	-0.16	-0.05	-0.77	-0.58
Design	3.74	0.07	1.14	-0.66	-0.32	-0.38	-0.70
Research	2.66	0.07	1.26	0.35	0.13	-0.88	-0.79
Promoting diversity	2.46	0.07	1.20	0.40	0.24	-0.68	-0.76
Liability	3.71	0.06	1.03	-0.56	-0.24	-0.23	-0.53
Cross-fn familiarity	3.52	0.06	1.00	-0.60	-0.15	0.06	-0.31
Flexibility	4.14	0.05	0.78	-0.60	-0.37	-0.19	-0.59
Meeting skills	3.86	0.06	1.00	-0.78	-0.31	0.29	-0.54
Coordinating	3.91	0.06	1.08	-0.97	-0.39	0.31	-0.63
Entrepreneurship	2.72	0.07	1.15	0.14	0.10	-0.69	-0.59
Marketing	2.89	0.07	1.29	0.01	0.07	-1.03	-0.82
Safety	3.26	0.07	1.26	-0.35	-0.08	-0.87	-0.78
Focus	3.64	0.06	1.03	-0.57	-0.20	-0.24	-0.45
Leading	3.71	0.06	1.12	-0.69	-0.28	-0.23	-0.66
Decision-making	4.33	0.05	0.78	-1.30	-0.63	2.12	-0.43
Managing	4.17	0.06	1.00	-1.32	-0.60	1.39	-0.58
Networking	3.75	0.06	1.03	-0.67	-0.26	-0.07	-0.53
Supervising	3.65	0.06	1.10	-0.69	-0.23	-0.17	-0.56
Risk-taking	3.46	0.06	1.05	-0.44	-0.14	-0.35	-0.43
Workplace politics	3.29	0.06	1.12	-0.35	-0.08	-0.51	-0.52
Self-motivation	4.29	0.04	0.66	-0.68	-0.37	0.99	-0.54
Citizenship	2.36	0.07	1.15	0.49	0.27	-0.59	-0.71
Action orientation	3.97	0.05	0.82	-0.74	-0.27	0.69	-0.23
Keeping up to date	3.41	0.06	1.03	-0.36	-0.11	-0.32	-0.38
Info-management	3.99	0.05	0.86	-0.49	-0.29	-0.46	-0.67
Managing development	3.85	0.05	0.88	-0.60	-0.24	0.21	-0.34
Self-management	4.49	0.04	0.66	-1.06	-0.79	0.58	-0.41
Ethics	4.22	0.05	0.88	-1.10	-0.58	0.93	-0.52
Commitment	4.40	0.04	0.67	-0.88	-0.60	0.48	-0.50
Concern for others	4.01	0.05	0.87	-0.67	-0.34	0.01	-0.51
Community	3.20	0.07	1.17	-0.31	-0.05	-0.70	-0.59
Loyalty	3.86	0.05	0.91	-0.52	-0.26	-0.22	-0.48
Honesty	4.38	0.04	0.71	-1.09	-0.62	1.56	-0.45
Demeanour	4.17	0.05	0.79	-0.42	-0.42	-0.47	-0.47

Note: The competencies are identified by their short names. The full names are listed in the same order in Table 1.

Table 31. Distribution statistics for Survey 2 of 250 senior engineers

Competency importance ratings (Missing values replaced by medians) (1 = not needed; 5 = critical)							
Competency	Mean	SE of		Skew		Kurtosis	
		Mean	SD	(± 0.15)		(±0.31)	
				Raw	Trans- formed	Raw	Trans- formed
Diversity skills	3.41	0.06	0.96	-0.43	-0.11	-0.11	-0.23
Interdisc. skills	3.98	0.05	0.74	-0.57	-0.21	0.75	-0.09
Mentoring	3.47	0.06	0.91	-0.42	-0.13	-0.10	-0.15
Teamwork	4.50	0.04	0.62	-0.94	-0.74	0.35	-0.45
Written comm.	4.40	0.04	0.63	-0.86	-0.47	1.12	-0.49
Managing comm.	4.29	0.04	0.61	-0.46	-0.26	0.55	-0.24
Negotiation	3.85	0.04	0.69	-0.24	-0.11	0.03	-0.01
Presenting	3.73	0.05	0.78	-0.35	-0.12	-0.14	-0.20
English	4.12	0.05	0.73	-0.63	-0.29	0.77	-0.33
Graphical comm.	4.15	0.05	0.76	-0.64	-0.35	0.35	-0.52
Verbal comm.	4.34	0.04	0.58	-0.21	-0.25	-0.66	-0.57
Working internat.	2.13	0.07	1.09	0.62	0.41	-0.65	-0.73
Theory	3.76	0.06	1.00	-0.57	-0.25	-0.30	-0.50
Aesthetics	2.84	0.06	0.92	-0.06	0.00	-0.36	-0.19
Life-cycle	3.62	0.05	0.87	-0.25	-0.12	-0.22	-0.25
Practical	4.28	0.04	0.68	-0.72	-0.39	0.58	-0.41
Maintainability	3.58	0.05	0.84	-0.66	-0.16	0.69	0.05
Manufacturability	2.96	0.07	1.12	-0.20	-0.01	-0.89	-0.48
Sustainability	3.44	0.06	0.90	-0.35	-0.11	-0.29	-0.17
Reliability	3.96	0.05	0.86	-0.73	-0.29	0.49	-0.33
Social context	3.05	0.06	0.98	-0.15	-0.03	-0.49	-0.26
Generalisation	3.25	0.06	0.91	-0.29	-0.09	-0.32	-0.15
Modelling	3.38	0.06	1.00	-0.45	-0.11	-0.27	-0.27
Problem-solving	4.41	0.04	0.69	-0.97	-0.67	0.58	-0.49
Sourcing info	4.14	0.04	0.64	-0.41	-0.20	0.59	0.02
Critical thinking	4.12	0.04	0.67	-0.55	-0.23	0.69	-0.08
Creativity	4.05	0.04	0.70	-0.43	-0.21	0.25	-0.15
Embracing change	3.80	0.05	0.84	-0.27	-0.14	-0.49	-0.50
Integrated design	3.17	0.06	1.02	-0.20	-0.05	-0.38	-0.30
3D skills	3.14	0.07	1.07	-0.14	-0.04	-0.69	-0.40
Systems	3.61	0.05	0.84	-0.42	-0.13	0.18	-0.11
Design	3.93	0.06	0.90	-0.55	-0.30	-0.29	-0.55
Research	2.85	0.07	1.06	0.22	0.04	-0.54	-0.38
Promoting diversity	2.63	0.06	1.01	0.11	0.08	-0.66	-0.41
Liability	3.73	0.06	0.90	-0.66	-0.19	0.51	-0.22
Cross-fn familiarity	3.46	0.05	0.81	-0.44	-0.12	0.33	0.04
Flexibility	3.98	0.04	0.69	-0.49	-0.18	0.56	0.07
Meeting skills	3.73	0.05	0.83	-0.75	-0.19	0.99	0.06
Coordinating	3.96	0.05	0.78	-0.63	-0.24	0.58	-0.15
Entrepreneurship	2.95	0.07	1.07	-0.02	0.01	-0.57	-0.40

Marketing	3.22	0.07	1.12	-0.31	-0.07	-0.68	-0.47
Safety	3.62	0.07	1.03	-0.39	-0.20	-0.46	-0.51
Focus	3.79	0.05	0.80	-0.37	-0.16	0.07	-0.17
Leading	3.86	0.06	0.91	-0.62	-0.27	0.13	-0.42
Decision-making	4.37	0.04	0.65	-0.82	-0.49	0.75	-0.47
Managing	4.19	0.05	0.76	-0.84	-0.37	1.28	-0.55
Networking	3.56	0.05	0.78	-0.43	-0.11	0.53	0.06
Supervising	3.85	0.05	0.84	-0.66	-0.22	0.51	-0.15
Risk-taking	3.49	0.06	0.97	-0.31	-0.12	-0.40	-0.33
Workplace politics	3.21	0.06	1.00	-0.17	-0.05	-0.45	-0.29
Self-motivation	4.29	0.04	0.61	-0.35	-0.27	-0.03	-0.32
Citizenship	2.53	0.06	0.95	0.06	0.09	-0.45	-0.35
Action orientation	4.12	0.04	0.65	-0.20	-0.17	-0.26	-0.27
Keeping up to date	3.53	0.05	0.82	-0.33	-0.10	0.18	-0.05
Info-management	3.85	0.05	0.73	-0.20	-0.11	-0.26	-0.24
Managing development	3.80	0.05	0.77	-0.54	-0.12	1.03	-0.11
Self-management	4.32	0.04	0.65	-0.41	-0.36	-0.70	-0.81
Ethics	4.42	0.04	0.70	-1.02	-0.72	0.53	-0.48
Commitment	4.52	0.04	0.56	-0.63	-0.61	-0.65	-0.71
Concern for others	4.14	0.05	0.71	-0.34	-0.27	-0.51	-0.56
Community	3.19	0.06	0.96	-0.33	-0.07	-0.21	-0.20
Loyalty	4.05	0.05	0.74	-0.62	-0.26	0.80	-0.20
Honesty	4.49	0.04	0.70	-1.67	-0.83	4.35	-0.32
Demeanour	4.14	0.05	0.76	-0.90	-0.34	1.32	-0.24

Note: The competencies are identified by their short names. The full names are listed in the same order in Table 1.

Appendix XXIII. Factor Analysis Overview and Application to CEG Project

1. Factor Analysis

Basilevsky (1994, p.98) explains the objective of factor analysis as attempting to represent “a large set of data by means of a parsimonious set of linear relations which in turn can be considered as newly created random variables”. Factor analysis is outlined by Tabachnick and Fidell (2001), Thompson (2004) and Brown (2006). A concise summary is provided by Russell (2002). Basilevsky (1994) and Gorsuch (1983) include more mathematical detail than most other books. Meyers *et al.* (2006) clearly describe applications of factor analysis, including useful summaries of recommendations from earlier references. All factor analysis extraction methods model a matrix of one of several available bivariate association coefficients between data, with a replica that highlights patterns in the data by diagonalizing the matrix, and thereby identifying a set of eigenvectors known as “factors”. Each variable is represented as a weighted sum of terms arising from variance shared by multiple variables, a term unique to the variable, and an error term.

Factor analysis that identifies factors from the bivariate association matrix, without a pre-specified structure nominating the number of factors and the variables reflecting each factor, is called exploratory factor analysis. In contrast, “confirmatory factor analysis” tests how well a pre-specified theoretical factor structure fits a set of data. This study used exploratory factor analysis in order to identify factors based on the survey data rather than theory. Exploratory factor analysis of intervally scaled data commonly uses the Pearson r bivariate correlation matrix, rather than the covariance matrix commonly used for confirmatory factor analysis, as the matrix of bivariate association coefficients on which analysis is based,.

1.1. Fundamental Definitions for Factor Analysis

The following fundamental equations for factor analysis are extracted, with minor modifications, from Tabachnick and Fidell (2001, pp. 590-595). Given a correlation matrix $\mathbf{R}$, this can be diagonalized to:

$$\mathbf{L} = \mathbf{V}^T \mathbf{R} \mathbf{V}$$

where $\mathbf{L}$ is a diagonal matrix with eigenvalues of $\mathbf{R}$ on the diagonal and

$\mathbf{V}$ is the matrix of eigenvectors of $\mathbf{R}$.

Only the eigenvectors with the highest eigenvalues are used. Therefore, the dimension of $\mathbf{L}$ is smaller than that of $\mathbf{R}$. The number of eigenvectors, or factors, retained is one of the decisions made during factor analysis, and can be based on both statistical and conceptual reasoning. This is discussed later.

The factor “loading” matrix is:

$$\mathbf{A} = \mathbf{V} \sqrt{\mathbf{L}}$$

Unless the matrix has been rotated obliquely, as discussed below, a_{ij} is the correlation between the i^{th} variable and the j^{th} factor. The “communality” coefficient for a variable is the proportion of that variable’s variance that is accounted for across all factors. With orthogonal factors, the communality for a given variable is the sum of the squared loadings across all factors.

There are several extraction methods available to identify the factors from the correlation matrix. The extraction method, principal components analysis, diagonalizes the complete correlation matrix, thereby representing each variable as a weighted sum of factors only, with no terms representing error or variance unique to the variable. Principal components analysis is frequently suggested to be distinct from factor analysis. However, as noted by Basilevsky (1994), strict distinction is not mathematically warranted because both are related. Extraction methods other than principal components analysis, rather than replicating the complete correlation matrix,

replicate a correlation matrix with reduced positive diagonal elements, or, for maximum likelihood extraction, manipulated off-diagonal elements. Each variable is then represented as a weighted sum of terms arising from variance shared by multiple variables, and additionally a term arising from variance unique to the individual variable, and an error term.

The factors are orthogonal after extraction. Rotation can then be used to display the factors more clearly. Some rotation methods transform the factors such that they can be oblique, rather than orthogonal. In this case the factors are correlated and the factor structure is presented as at least two from three resulting matrices, rather than a single loading matrix. The three matrices are the “structure” matrix, in which each element is the correlation between a variable and a factor, the “pattern” matrix in which each element is the weight in the sum of weighted variables that form a factor, and the factor correlation matrix.

2. Application of Factor Analysis to the CEG Project

Survey 1 had asked engineers to rate the importance of competencies for their own jobs. Exploratory factor analysis was conducted to identify factors of competencies with correlated ratings of importance.

2.1. Extraction Method for the CEG Project

Although principal components analysis is commonly used (Russell 2002), it was not considered appropriate here. Principal components analysis is suitable for reducing variables to a smaller number of factors containing as much as possible of the original data, in order to simplify further analysis (Fabrigar *et al.* 1999). Other extraction methods identify factors arising from correlated data, rather than maintaining all of the variation in the data. Principal axis factoring, also known as “principal factors”, was

used because it is more robust to non-normality than the maximum likelihood extraction method (Floyd and Widaman 1995, Fabrigar *et al.* 1999). Principal axis factoring replaces the ones on the positive diagonal of the correlation matrix with communality coefficients. The communalities are initially estimated from a principal components analysis, and refined iteratively by repeating the factor analysis until the result is stable (Thompson 2004). The purpose of modifying the correlation matrix is to remove measurement error and variance unique to individual variables from the factor extraction. As recommended by Thompson, principal components analysis results were compared with the other factor analysis results.

2.2. Rotation Method for the CEG Project

The DeSeCo Project framework stated that competencies do not exist in isolation but as “constellations” of competencies depending on each other (OECD 2002, p.14).

Therefore, an oblique (direct oblimin) rotation was performed, rather than an orthogonal rotation which would have forced the factors to be uncorrelated. The SPSSTM default delta parameter ($\delta = 0$), which controls the level of correlation between factors, was used.

2.3. Refinement of the Factor Model

There are differing recommendations about how to select the variables to reflect each factor from those identified by the factor analysis, and about which matrices to use to inform this process if an oblique rotation is used (Meyers *et al.* 2006). It is commonly recommended that variables reflecting a factor should be excluded if their loading is below a minimum value. However, there are multiple recommendations for determining the minimum value, and other considerations that affect the decision. Additionally, there are varied recommendations about whether the pattern matrix, the structure matrix, or

both, should influence decisions about which variables are included to reflect each factor.

In this study, an oblique rotation was used because the theoretical framework expects that competency factors could be correlated. The pattern matrix, which defines the oblique factors in terms of the reflecting variables, was therefore used to identify the variables that the statistical algorithm allocated to each factor.

Although it was considered appropriate for factors to be oblique, it would be unhelpful for applications of the results if the allocation of variables among the factors was confusing. Therefore, discriminant validity of the factor structure was sought. To finally test and refine the discriminant validity of the preferred factor structure, the structure matrix was used because this matrix shows the correlation between factors and the variables reflecting them. The structure matrix revealed any variable that was more strongly correlated with a factor it was not allocated to reflect than with the factor it was allocated to reflect.

2.4. Suitability of Data for Factor Analysis

2.4.1. Intervally Scaled Data

If the data are interally scaled then factor analysis can be based on the Pearson r bivariate correlation matrix, or a reduced form of this, rather than Spearman's rho on which analysis of ordinal data is based (Thompson 2004). As discussed in section 5.1.3.2.1, only the endpoints of the rating scale for competency importance were labelled (1 = *not needed*; 5 = *critical*), so it could be assumed that participants spaced the points on the scale evenly, and therefore the competency ratings were considered to be interally scaled.

2.4.2. Sample Size

There are rules of thumb for determining the minimum sample size for factor analysis. For example, Tabachnick and Fidell (2001, p.588) refer to two examples and suggest that as a rule of thumb a sample size of 300 is “comforting”. However, MacCallum *et al.* (1999) demonstrate that the required sample size varies with the shared variance between the variables and the number of variables reflecting each factor. They argue that the required sample size is decreased by high shared variance between variables and high numbers of variables reflecting each factor. They recommend a mean level of communality of 0.7, a small range of communality values, and three to seven variables reflecting each factor, preferably closer to seven than three.

The communalities and number of variables reflecting each factor are estimated during the factor analysis and are presented in Chapter 7. The higher number of usable responses in Survey 1 ($N = 300$) than in Survey 2 ($N = 250$) suggested that Survey 1 was likely to be more suitable than Survey 2 for factor analysis.

Combining the responses of the two surveys would have provided a higher number of responses. However, this was inappropriate because the two surveys did not pose identical questions; observation of the distributions or the importance ratings had revealed different uses of the scale in the two surveys (section 6.5.2). Participants in Survey 2 were required to generalise, although participants in Survey 1 were not. Therefore, exploratory factor analysis was performed on the competency ratings from Survey 1.

2.4.3. Missing Values

Missing values would have needed to be addressed in the analysis. However, as discussed in section 5.1.3.5, these were few and had been imputed with medians.

2.4.4. Linearity and Multivariate Normality

Multivariate normality is assumed when statistical methods are used to determine the number of factors (Tabachnick and Fidell 2001). The competency ratings were transformed using the normalisation features of LISREL, to improve the normality among the single variables without altering the means or standard deviations. The skew and kurtosis values before and after transformation are presented in Appendix XXII.

2.4.5. Variation within Each Variable

Calculation of correlation coefficients requires sufficient variation between respondents' ratings (Foster *et al.* 2006). Each competency's ratings were considered to vary sufficiently across respondents (Appendix XXI).

2.4.6. Correlation between Variables

Other criteria are assessed during the analysis below. Factor analysis requires sufficient correlation between the variables. Values above 0.3 in the correlation matrix suggest sufficient correlation (Tabachnick and Fidell 2001). Tabachnick and Fidell also recommend checking that factors are present by checking that high bivariate correlations are accompanied by low bivariate correlations. They recommend using Bartlett's test of sphericity only with fewer than five responses per variable. Five responses per 64 competencies would be 320 responses. Therefore, based on Tabachnick and Fidell's advice, Bartlett's test could be on the borderline of being too sensitive to test the hypothesis that the correlations are not significant in this study ($N = 300$). For factorability of the data, Tabachnick and Fidell state that many correlations should be significant. Also for factorability, the anti-image correlation matrix should have "mostly small values among the off-diagonal elements" (p.589) and Kaiser's measure of sampling adequacy should be 0.6 or higher. These tests are reported with the results in Chapter 7.

Appendix XXIV. SPSS™ Syntax and Selected Output for Chapter 7

1. Factor Analysis of All 64 Survey 1 Competency

Ratings

```
/* Factor analysis using competency ratings normalised in LISREL
FACTOR
  /VARIABLES cn1 cn2 cn3 cn4 cn5 cn6 cn7 cn8 cn9 cn10 cn11 cn12
cn13 cn14 cn15 cn16 cn17 cn18 cn19 cn20 cn21 cn22 cn23 cn24 cn25
  cn26 cn27 cn28 cn29 cn30 cn31 cn32 cn33 cn34 cn35 cn36 cn37
cn38 cn39 cn40 cn41 cn42 cn43 cn44 cn45 cn46 cn47 cn48 cn49 cn50
  cn51 cn52 cn53 cn54 cn55 cn56 cn57 cn58 cn59 cn60 cn61 cn62
cn63 cn64
  /MISSING LISTWISE
  /ANALYSIS cn1 cn2 cn3 cn4 cn5 cn6 cn7 cn8 cn9 cn10 cn11 cn12
cn13 cn14 cn15 cn16 cn17 cn18 cn19 cn20 cn21 cn22 cn23 cn24 cn25
cn26
  cn27 cn28 cn29 cn30 cn31 cn32 cn33 cn34 cn35 cn36 cn37 cn38
cn39 cn40 cn41 cn42 cn43 cn44 cn45 cn46 cn47 cn48 cn49 cn50
  cn51 cn52 cn53 cn54 cn55 cn56 cn57 cn58 cn59 cn60 cn61 cn62
cn63 cn64
  /SELECT=Sample(1)
  /PRINT UNIVARIATE INITIAL CORRELATION SIG DET KMO INV REPR
AIC EXTRACTION ROTATION
  /FORMAT SORT
  /PLOT EIGEN
  /CRITERIA FACTORS(11) ITERATE(250)
  /EXTRACTION PAF
  /CRITERIA ITERATE(250) DELTA(0)
  /ROTATION OBLIMIN
  /METHOD=CORRELATION.
```

2. Factor Analysis of Selected 53 Survey 1

Competency Ratings

```
/* Step 11 with 11 vars deleted cn12 cn16 cn7 cn22 mentoring cn3
/* aestheticscn14 citizenship cn52 lifecycle cn15 promoting
/* diversity cn34 workplace politics cn50 self motivation cn51
FACTOR
  /VARIABLES cn1 cn2 cn4 cn5 cn6 cn8 cn9 cn10 cn11 cn13 cn17
cn18 cn19 cn20 cn21 cn23 cn24 cn25
  cn26 cn27 cn28 cn29 cn30 cn31 cn32 cn33 cn35 cn36 cn37 cn38
cn39 cn40 cn41 cn42 cn43 cn44 cn45 cn46 cn47 cn48 cn49
  cn53 cn54 cn55 cn56 cn57 cn58 cn59 cn60 cn61 cn62 cn63
cn64
  /MISSING LISTWISE
```

```

/ANALYSIS cn1 cn2 cn4 cn5 cn6 cn8 cn9 cn10 cn11 cn13 cn17
cn18 cn19 cn20 cn21 cn23 cn24 cn25 cn26
cn27 cn28 cn29 cn30 cn31 cn32 cn33 cn35 cn36 cn37 cn38
cn39 cn40 cn41 cn42 cn43 cn44 cn45 cn46 cn47 cn48 cn49
cn53 cn54 cn55 cn56 cn57 cn58 cn59 cn60 cn61 cn62 cn63
cn64
/SELECT=Sample(1)
/PRINT UNIVARIATE INITIAL CORRELATION SIG DET KMO INV REPR
AIC EXTRACTION ROTATION
/FORMAT SORT
/PLOT EIGEN
/CRITERIA FACTORS(11) ITERATE(250)
/EXTRACTION PAF
/CRITERIA ITERATE(250) DELTA(0)
/ROTATION OBLIMIN
/METHOD=CORRELATION.

```

3. Unidimensionality and Internal Reliability of Factors in Structure Arising from 53 Selected Competencies

3.1. Creativity / Problem-Solving Factor

```

/* Select Survey 1 data only
USE ALL.
COMPUTE filter_$=(Sample=1).
VARIABLE LABEL filter_$ 'Sample=1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
/* Creativity / Problem-Solving Factor
/* Critical thinking, Sourcing info, Creativity,
/* Embracing change, Problem-solving
/* Flexibility, Design, Systems
/* Check for unidimensionality
FACTOR
/VARIABLES cn26 cn25 cn27 cn28 cn24 cn37 cn31 cn32
/MISSING LISTWISE
/ANALYSIS cn26 cn25 cn27 cn28 cn24 cn37 cn31 cn32
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn26 cn25 cn27 cn28 cn24 cn37 cn31 cn32
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.

```

Figure 39. Scree plot for importance ratings of 8 competencies reflecting the Creativity / Problem-Solving Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.2. Applying Technical Theory Factor

```
/* Applying Technical Theory factor
Theory, 3D skills, Modelling, Research
/* Check for unidimensionality
FACTOR
/VARIABLES cn13 cn30 cn23 cn33
/MISSING LISTWISE
/ANALYSIS cn13 cn30 cn23 cn33
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn13 cn30 cn23 cn33
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 40. Scree plot for importance ratings of 4 competencies reflecting the Applying Technical Theory Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.3. Practical Engineering Factor

```
/* Practical Engineering Factor
/* Maintainability, Manufacturability, Reliability,
/* Integrated design
/* Check for unidimensionality
FACTOR
/VARIABLES cn17 cn18 cn20 cn29
/MISSING LISTWISE
/ANALYSIS cn17 cn18 cn20 cn29
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn17 cn18 cn20 cn29
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 41. Scree plot for importance ratings of 4 competencies reflecting the Practical Engineering Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.4. Professionalism Factor

```
/* Professionalism Factor
/*
Honesty, Loyalty, Commitment, Ethics, Demeanour, Concern for others
/* Check for unidimensionality
FACTOR
/VARIABLES cn63 cn62 cn59 cn58 cn64 cn60
/MISSING LISTWISE
/ANALYSIS cn63 cn62 cn59 cn58 cn64 cn60
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn63 cn62 cn59 cn58 cn64 cn60
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 42. Scree plot for importance ratings of 6 competencies reflecting the Professionalism Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.5. Innovation Factor

```
/* Innovation Factor
/*
Entrepreneurship, Marketing, Networking, Presenting, Keeping up
to date
/* Check for unidimensionality
FACTOR
/VARIABLES cn40 cn41 cn47 cn8 cn54
/MISSING LISTWISE
/ANALYSIS cn40 cn41 cn47 cn8 cn54
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn40 cn41 cn47 cn8 cn54
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 43. Scree plot for importance ratings of 5 competencies reflecting the Innovation Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.6. Contextual Responsibilities Factor

```
/* Contextual Responsibilities Factor
/* Sustainability, Social context, Community, Safety
/* Check for unidimensionality
FACTOR
/VARIABLES cn19 cn21 cn61 cn42
/MISSING LISTWISE
/ANALYSIS cn19 cn21 cn61 cn42
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn19 cn21 cn61 cn42
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 44. Scree plot for importance ratings of 4 competencies reflecting the Contextual Responsibilities Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.7. Management/Leadership Factor

```
/* Management/Leadership Factor
/* Supervising, Coordinating, Managing, Leading, Risk-taking,
/* Decision-making, Meeting skills
/* Check for unidimensionality
FACTOR
/VARIABLES cn48 cn39 cn44 cn46 cn49 cn38 cn45
/MISSING LISTWISE
/ANALYSIS cn48 cn39 cn44 cn46 cn49 cn38 cn45
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn48 cn39 cn44 cn46 cn49 cn38 cn45
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 45. Scree plot for importance ratings of 7 competencies reflecting the Management / Leadership Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.8. Communication Factor

```
/* Communication Factor
/* Graphical comm., English, Written comm., Verbal comm.
/* Check for unidimensionality
FACTOR
/VARIABLES cn10 cn9 cn11 cn5
/MISSING LISTWISE
/ANALYSIS cn10 cn9 cn11 cn5
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn10 cn9 cn11 cn5
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 46. Scree plot for importance ratings of 4 competencies reflecting the Communication Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.9. Engineering Business Factor

```
/* Engineering Business Factor
/* Eng Bus Liability, Cross-fn familiarity, Focus
/* Check for unidimensionality
FACTOR
/VARIABLES cn35 cn36 cn43
/MISSING LISTWISE
/ANALYSIS cn35 cn36 cn43
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn35 cn36 cn43
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 47. Scree plot for importance ratings of 3 competencies reflecting the Engineering Business Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.10. Self-Management Factor

```
/* Self-Management factor
/* Managing development, Info-management,
/* Self-management, Managing comm., Action orientation
/* Check for unidimensionality
FACTOR
  /VARIABLES cn56 cn57 cn55 cn6 cn53
  /MISSING LISTWISE
  /ANALYSIS cn56 cn57 cn55 cn6 cn53
  /SELECT=Sample(1)
  /PRINT INITIAL EXTRACTION
  /PLOT EIGEN
  /CRITERIA MINEIGEN(1) ITERATE(25)
  /EXTRACTION PC
  /ROTATION NOROTATE
  /METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
  /VARIABLES=cn56 cn57 cn55 cn6 cn53
  /SCALE('ALL VARIABLES') ALL
  /MODEL=ALPHA.
```

Figure 48. Scree plot for importance ratings of 5 competencies reflecting the Self-Management Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

3.11. Working in Diverse Teams Factor

```
/* Working in Diverse Teams Factor
/* Interdisc. Skills, Diversity skills, Teamwork
/* Check for unidimensionality
FACTOR
/VARIABLES cn1 cn2 cn4
/MISSING LISTWISE
/ANALYSIS cn1 cn2 cn4
/SELECT=Sample(1)
/PRINT INITIAL EXTRACTION
/PLOT EIGEN
/CRITERIA MINEIGEN(1) ITERATE(25)
/EXTRACTION PC
/ROTATION NOROTATE
/METHOD=CORRELATION.
/* Internal reliability
RELIABILITY
/VARIABLES=cn1 cn2 cn4
/SCALE('ALL VARIABLES') ALL
/MODEL=ALPHA.
```

Figure 49. Scree plot for importance ratings of 3 competencies reflecting the Working in Diverse Teams Factor in the 53 competency factor structure, using ratings made by established engineers in Survey 1 ($N = 300$)

4. Definition and Calculation of Factor Scores

```
/* Define factor scores using competency ratings that have
medians replacing missing values but that are not normalised
COMPUTE probsolvefactornotn = MEAN(c26_1, c25_1, c27_1, c28_1,
c24_1, c37_1, c31_1, c32_1) .
EXECUTE .
COMPUTE techtheoryfactornotn = MEAN(c13_1, c30_1, c23_1, c33_1)
.
EXECUTE .
COMPUTE practicalengfactornotn = MEAN(c17_1, c18_1, c20_1,
c29_1) .
EXECUTE .
COMPUTE professionalismfactornotn = MEAN(c63_1, c62_1, c59_1,
c58_1, c64_1, c60_1) .
EXECUTE .
COMPUTE innovationfactornotn = MEAN(c40_1, c41_1, c47_1, c8_1,
c54_1) .
EXECUTE .
COMPUTE responsibilityfactornotn = MEAN(c19_1, c21_1, c61_1,
c42_1) .
EXECUTE .
COMPUTE manageleadfactornotn = MEAN(c48_1, c39_1, c44_1, c46_1,
c49_1, c38_1, c45_1) .
EXECUTE .
COMPUTE communicationfactornotn = MEAN(c10_1, c9_1, c11_1, c5_1)
.
EXECUTE .
COMPUTE engbusinessfactornotn = MEAN(c35_1, c36_1, c43_1) .
EXECUTE .
COMPUTE selfmanagefactornotn = MEAN(c56_1, c57_1, c55_1, c6_1,
c53_1) .
EXECUTE .
COMPUTE diverset teamworkfactornotn = MEAN(c1_1, c2_1, c4_1) .
EXECUTE .

/* Label the factors
/* notn refers to the use of competency ratings that have not
/* been normalised using LISREL
VARIABLE LABELS probsolvefactornotn 'Creativity / Problem
solving'
techtheoryfactornotn 'Applying Technical Theory'
practicalengfactornotn 'Practical Engineering'
professionalismfactornotn 'Professionalism'
innovationfactornotn 'Innovation'
responsibilityfactornotn 'Contextual Responsibilities'
manageleadfactornotn 'Management/Leadership'
communicationfactornotn 'Communication'
engbusinessfactornotn 'Engineering Business'
selfmanagefactornotn 'Self-Management'
diverset teamworkfactornotn 'Working in Diverse Teams'.
```

5. Frequency Distributions for the Generic Engineering Competency Factors

Using data from Survey 1

```
/*Calculate mean factor importance ratings across Survey 1
competency ratings

/* Select Survey 1 data only
USE ALL.
  COMPUTE filter_$=(Sample=1).
  VARIABLE LABEL filter_$ 'Sample=1 (FILTER)'.
  VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
  FORMAT filter_$ (f1.0).
  FILTER BY filter_$.
  EXECUTE.

/* Frequency statistics and frequency distributions
FREQUENCIES VARIABLES=probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
  responsibilityfactornotn manageleadfactornotn
communicationfactornotn
  engbusinessfactornotn selfmanagefactornotn
diverseteamworkfactornotn
  /STATISTICS=STDDEV SEMEAN MEAN SKEWNESS SESKEW KURTOSIS SEKURT
  /BARCHART FREQ
  /ORDER=ANALYSIS.
```

Figure 50. Frequency distribution for Creativity / Problem-Solving Factor importance across responses from established engineers in Survey 1 (N = 300)

Figure 51. Frequency distribution for Applying Technical Theory Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 52. Frequency distribution for Practical Engineering Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 53. Frequency distribution for Professionalism Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 54. Frequency distribution for Innovation Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 55. Frequency distribution for Contextual Responsibilities Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 56. Frequency distribution for Management/Leadership Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 57. Frequency distribution for Communication Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 58. Frequency distribution for Engineering Business Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 59. Frequency distribution for Self-Management Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Figure 60. Frequency distribution for Working in Diverse Teams Factor importance across responses from established engineers in Survey 1 ($N = 300$)

Appendix XXV. SPSS™ Syntax and Selected Output for Chapter 8

1. Example of Normality Check in Preparation for MANOVA

```
/* Select Survey 1 data
USE ALL.
COMPUTE filter_$=(Sample = 1).
VARIABLE LABEL filter_$ 'Sample = 1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
/* normality check and box plot in preparation for MANOVA
/* comparing generic competency factor importance ratings
/* with country in which participant was awarded undergraduate
/* engineering qualification
EXAMINE VARIABLES=probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn responsibilityfactornotn
manageleadfactornotn communicationfactornotn
engbusinessfactornotn selfmanagefactornotn
diverseteamworkfactornotn BY Becountry
/PLOT BOXPLOT STEMLEAF NPLOT
/COMPARE GROUP
/STATISTICS DESCRIPTIVES
/CINTERVAL 95
/MISSING LISTWISE
/NOTOTAL.
```

2. MANOVAs to Check for Confounds

```
/* Country of Undergrad engineering studies
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
BY Age
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Age.
```

```
/* Possession of non-technical qualifications
```

```
GLM probsolvefactor notn techtheoryfactor notn  
practicalengfactor notn professionalismfactor notn  
innovationfactor notn responsibilityfactor notn  
manageleadfactor notn communicationfactor notn  
engbusinessfactor notn selfmanagefactor notn  
diverse teamworkfactor notn  
  BY NontechQual  
/METHOD=SSTYPE(3)  
/INTERCEPT=INCLUDE  
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY  
/CRITERIA=ALPHA(.05)  
  
/DESIGN= NontechQual.
```

```
/* Gender
```

```
GLM probsolvefactor notn techtheoryfactor notn  
practicalengfactor notn professionalismfactor notn  
innovationfactor notn  
responsibilityfactor notn manageleadfactor notn  
communicationfactor notn engbusinessfactor notn  
selfmanagefactor notn diverse teamworkfactor notn  
  BY Gender  
/METHOD=SSTYPE(3)  
/INTERCEPT=INCLUDE  
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY  
/CRITERIA=ALPHA(.05)  
  
/DESIGN= Gender.
```

```
/* Age
```

```
GLM probsolvefactor notn techtheoryfactor notn  
practicalengfactor notn professionalismfactor notn  
innovationfactor notn  
responsibilityfactor notn manageleadfactor notn  
communicationfactor notn engbusinessfactor notn  
selfmanagefactor notn diverse teamworkfactor notn  
  BY Age  
/METHOD=SSTYPE(3)  
/INTERCEPT=INCLUDE  
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY  
/CRITERIA=ALPHA(.05)  
  
/DESIGN= Age.
```

```
/* Whether participant was working in WA among those working in  
/* Australia
```

```
/* Define variable for whether participants who were working in  
/* Australia were working in WA
```

```
FILTER OFF.  
USE ALL.
```

```

EXECUTE.
USE ALL.
/* WorkLoc 1 is Australia
COMPUTE filter_$=(WorkLoc=1).
VARIABLE LABEL filter_$ 'WorkLoc=1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.
RECODE StateCorrected ('WA'=1) (ELSE=2) INTO WAorNot.
VARIABLE LABELS WAorNot 'WA or Not'.
EXECUTE.
USE ALL.
COMPUTE filter_$=(WorkLoc=1 AND Sample = 1).
VARIABLE LABEL filter_$ 'WorkLoc=1 AND Sample = 1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.

/* MANOVA checking whether overrepresentation of WA participants
/* among Aust participants affected results using new variable
/* WAorNot
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
BY WAorNot
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)

/DESIGN= WAorNot.

/* Country of secondary education

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
BY SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)

/DESIGN= SecCountry.

/* Whether undergrad engineering qualification was from UWA

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn

```

```

responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
    BY UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)

/DESIGN= UWAOther.

/* Level of technical qualification

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
    BY TechQual
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=TechQual(TUKEY T2)
/PLOT=PROFILE(TechQual)
/EMMEANS=TABLES(TechQual)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)

/DESIGN= TechQual.

```

3. MANOVAs to Study Relationship of Importance of Competency Importance Factors with Work Context

```

/* Engineering discipline
/* Also checking for interaction with whether participant was a
/* UWA graduate

COMPUTE filter_$=(Sample=1).
VARIABLE LABEL filter_$ 'Sample=1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
    BY Discipline UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Discipline(TUKEY)

```

```

/PLOT=PROFILE(Discipline*UWAOther)
/EMMEANS=TABLES(Discipline)
/EMMEANS=TABLES(Discipline*UWAOther)
/EMMEANS=TABLES(UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Discipline UWAOther Discipline*UWAOther.

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
  BY Discipline SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Discipline(TUKEY)
/PLOT=PROFILE(Discipline* SecCountry)
/EMMEANS=TABLES(Discipline)
/EMMEANS=TABLES(Discipline* SecCountry)
/EMMEANS=TABLES(SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Discipline SecCountry Discipline* SecCountry.

/* discipline
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
  BY Discipline
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Discipline(TUKEY)
/PLOT=PROFILE(Discipline)
/EMMEANS=TABLES(Discipline)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Discipline .

/* work location Aust or overseas
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
  responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn
  diverseteamworkfactor notn
  BY WorkLoc
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/EMMEANS=TABLES(WorkLoc)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)

```

```

/DESIGN= WorkLoc.

/* RmtLoc Percentage of participants work time spent in regional
/* remote or offshore locations 0 to 33 OR 34 to 100
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn
diverseteamworkfactor notn
BY RmtLoc
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/EMMEANS=TABLES(RmtLoc)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= RmtLoc.

/* Check for interaction between RmtLoc and UWAOther
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
BY RmtLoc UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(RmtLoc* UWAOther)
/EMMEANS=TABLES(RmtLoc)
/EMMEANS=TABLES(RmtLoc* UWAOther)
/EMMEANS=TABLES(UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= RmtLoc UWAOther RmtLoc* UWAOther.

/* Check for interaction between RmtLoc and SecCountry
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
BY RmtLoc SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(RmtLoc* SecCountry)
/EMMEANS=TABLES(RmtLoc)
/EMMEANS=TABLES(RmtLoc* SecCountry)
/EMMEANS=TABLES(SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= RmtLoc SecCountry RmtLoc* SecCountry.

/* Years that participants organization had provided current
main service or products 0 to 3 OR Over 3

```



```

GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
    responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn
    diverseteamworkfactor notn
    BY YrsProdServ
    /METHOD=SSTYPE(3)
    /INTERCEPT=INCLUDE
    /EMMEANS=TABLES(YrsProdServ)
    /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
    /CRITERIA=ALPHA(.05)
    /DESIGN= YrsProdServ.

/* Check for interaction between YrsProdServ and UWAOther
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
    BY YrsProdServ UWAOther
    /METHOD=SSTYPE(3)
    /INTERCEPT=INCLUDE
    /PLOT=PROFILE(YrsProdServ* UWAOther)
    /EMMEANS=TABLES(YrsProdServ)
    /EMMEANS=TABLES(YrsProdServ* UWAOther)
    /EMMEANS=TABLES(UWAOther)
    /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
    /CRITERIA=ALPHA(.05)
    /DESIGN= YrsProdServ UWAOther YrsProdServ* UWAOther.

/* Check for interaction between YrsProdServ and SecCountry
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverseteamworkfactor notn
    BY YrsProdServ SecCountry
    /METHOD=SSTYPE(3)
    /INTERCEPT=INCLUDE
    /PLOT=PROFILE(YrsProdServ* SecCountry)
    /EMMEANS=TABLES(YrsProdServ)
    /EMMEANS=TABLES(YrsProdServ* SecCountry)
    /EMMEANS=TABLES(SecCountry)
    /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
    /CRITERIA=ALPHA(.05)
    /DESIGN= YrsProdServ SecCountry YrsProdServ* SecCountry.

/* sector
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn

```

```

selfmanagefactornotn diverseteamworkfactornotn
  BY Sector
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Sector(TUKEY)
/PLOT=PROFILE(Sector)
/EMMEANS=TABLES(Sector)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Sector .

/* Check for interaction between Sector and SecCountry
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY Sector SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Sector(TUKEY)
/PLOT=PROFILE(Sector* SecCountry)
/EMMEANS=TABLES(Sector)
/EMMEANS=TABLES(Sector* SecCountry)
/EMMEANS=TABLES(SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Sector SecCountry Sector* SecCountry.

/* Check for interaction between Sector and UWAOther
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY Sector UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Sector(TUKEY)
/PLOT=PROFILE(Sector* UWAOther)
/EMMEANS=TABLES(Sector)
/EMMEANS=TABLES(Sector* UWAOther)
/EMMEANS=TABLES(UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Sector UWAOther Sector* UWAOther.

/* Organization Size
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn

```

```

selfmanagefactornotn diverseteamworkfactornotn
  BY NmEmployees
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /POSTHOC=NmEmployees(TUKEY)
  /PLOT=PROFILE(NmEmployees)
  /EMMEANS=TABLES(NmEmployees)
  /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
  /CRITERIA=ALPHA(.05)
  /DESIGN= NmEmployees .

/* Check for interaction between NmEmployees and SecCountry
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY NmEmployees SecCountry
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /POSTHOC=NmEmployees(TUKEY)
  /PLOT=PROFILE(NmEmployees* SecCountry)
  /EMMEANS=TABLES(NmEmployees)
  /EMMEANS=TABLES(NmEmployees* SecCountry)
  /EMMEANS=TABLES(SecCountry)
  /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
  /CRITERIA=ALPHA(.05)
  /DESIGN= NmEmployees SecCountry NmEmployees* SecCountry.

/* Check for interaction between NmEmployees and UWAOther
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY NmEmployees UWAOther
  /METHOD=SSTYPE(3)
  /INTERCEPT=INCLUDE
  /POSTHOC=NmEmployees(TUKEY)
  /PLOT=PROFILE(NmEmployees* UWAOther)
  /EMMEANS=TABLES(NmEmployees)
  /EMMEANS=TABLES(NmEmployees* UWAOther)
  /EMMEANS=TABLES(UWAOther)
  /PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
  /CRITERIA=ALPHA(.05)
  /DESIGN= NmEmployees UWAOther NmEmployees* UWAOther.

/* Technical Extent to which participant's role was technical
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn

```

```

selfmanagefactornotn diverseteamworkfactornotn
  BY Technical
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Technical(TUKEY)
/PLOT=PROFILE(Technical)
/EMMEANS=TABLES(Technical)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Technical .

/* Check for interaction between Technical and SecCountry
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY Technical SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Technical(TUKEY)
/PLOT=PROFILE(Technical* SecCountry)
/EMMEANS=TABLES(Technical)
/EMMEANS=TABLES(Technical* SecCountry)
/EMMEANS=TABLES(SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Technical SecCountry Technical* SecCountry.

/* Check for interaction between Technical and UWAOther
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
  BY Technical UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/POSTHOC=Technical(TUKEY)
/PLOT=PROFILE(Technical* UWAOther)
/EMMEANS=TABLES(Technical)
/EMMEANS=TABLES(Technical* UWAOther)
/EMMEANS=TABLES(UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= Technical UWAOther Technical* UWAOther.

```

4. MANOVAs to Study Relationship of Importance of Competency Importance Factors with Key Responsibilities

```
/* 8 Key Responsibilities coded as binary variables
USE ALL.
COMPUTE filter_$=(Sample=1).
VARIABLE LABEL filter_$ 'Sample=1 (FILTER)'.
VALUE LABELS filter_$ 0 'Not Selected' 1 'Selected'.
FORMAT filter_$ (f1.0).
FILTER BY filter_$.
EXECUTE.

/* Key Responsibility Construction supervision
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn
diverse teamworkfactor notn
BY ConSupKR
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/EMMEANS=TABLES(ConSupKR)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= ConSupKR.

/* Check for interaction between ConSupKR and UWAOther
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverse teamworkfactor notn
BY ConSupKR UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(ConSupKR* UWAOther)
/EMMEANS=TABLES(ConSupKR)
/EMMEANS=TABLES(ConSupKR* UWAOther)
/EMMEANS=TABLES(UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= ConSupKR UWAOther ConSupKR* UWAOther.

/* Check for interaction between ConSupKR and SecCountry
GLM probsolvefactor notn techtheoryfactor notn
practicalengfactor notn professionalismfactor notn
innovationfactor notn
responsibilityfactor notn manageleadfactor notn
communicationfactor notn engbusinessfactor notn
selfmanagefactor notn diverse teamworkfactor notn
```

```

        BY ConSupKR SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(ConSupKR* SecCountry)
/EMMEANS=TABLES(ConSupKR)
/EMMEANS=TABLES(ConSupKR* SecCountry)
/EMMEANS=TABLES(SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= ConSupKR SecCountry ConSupKR* SecCountry.

/* Similarly

/* Key Responsibility Design ...

/* Key Responsibility Management ...

/* Key Responsibility ProdMntKR Production Quality Maintenance ...
/* Only significant result of this MANOVA was one factor less
/* important for participants with the key responsibility
/* Result not of sufficient consequence to be reported in thesis

/* Key Responsibility StdAnlKR Project Study / Analysis ...
/* No significant result from this MANOVA
/* Therefore result not reported

/* Key Responsibility RDKR Research and Development incl
/* Product Design and Development ...

/* Key Responsibility SalesKR Sales Marketing ...

/* Key Responsibility TchngKR Teaching Training ...
/* Multivariate test was not significant
/* Therefore this MANOVA not reported in thesis

```

5. MANOVAs to Study Relationship of Importance of Competency Importance Factors with Task Groups

```

/*Task TskAllEngPracLev2 Engineering practice
/* Lev2 is a binary variable where
/* 1 means participant does at least half of the tasks in
/* the category
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn
diverseteamworkfactornotn
BY TskAllEngPracLev2
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE

```

```

/EMMEANS=TABLES (TskAllEngPracLev2)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
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/DESIGN= TskAllEngPracLev2.

/* check for interaction between TskAllEngPracLev2 and UWAOther
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
    BY TskAllEngPracLev2 UWAOther
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(TskAllEngPracLev2* UWAOther)
/EMMEANS=TABLES (TskAllEngPracLev2)
/EMMEANS=TABLES (TskAllEngPracLev2* UWAOther)
/EMMEANS=TABLES (UWAOther)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= TskAllEngPracLev2 UWAOther TskAllEngPracLev2*
UWAOther.

/* Check for interaction between TskAllEngPracLev2 and
/* SecCountry
GLM probsolvefactornotn techtheoryfactornotn
practicalengfactornotn professionalismfactornotn
innovationfactornotn
responsibilityfactornotn manageleadfactornotn
communicationfactornotn engbusinessfactornotn
selfmanagefactornotn diverseteamworkfactornotn
    BY TskAllEngPracLev2 SecCountry
/METHOD=SSTYPE(3)
/INTERCEPT=INCLUDE
/PLOT=PROFILE(TskAllEngPracLev2* SecCountry)
/EMMEANS=TABLES (TskAllEngPracLev2)
/EMMEANS=TABLES (TskAllEngPracLev2* SecCountry)
/EMMEANS=TABLES (SecCountry)
/PRINT=DESCRIPTIVE ETASQ RSSCP HOMOGENEITY
/CRITERIA=ALPHA(.05)
/DESIGN= TskAllEngPracLev2 SecCountry TskAllEngPracLev2*
SecCountry.

/* Similarly
/*Task DsgnLev2 Design Task Group ...

/*Task TskMngtLev2 Project engineering Engineering project
/* management Task Group ...

/*Task TskOprtnsLev2 Engineering operations Task Group ...

/*Task TskBusLev2 Business management development Task Group ...

/*Task TskMatLev2 Materials Components Systems Task Group ...

/*Task TskEnvLev2 Environmental Management Task Group ...

```

```
/*Task TskInvstLev2 Investigation and Reporting Task Group ...  
/*Task TskResLev2 Research Development Commercialisation Task  
/* Group ...  
/*Task TskChgLev2 Change Technical Development Task Group ...  
/*Task TskTechLev2 Tech Sales Promotion Task Group ...  
/*Task TskTeachLev2 Teaching Task Group ...
```


Appendix XXVI. Email Invitation to Participate in Focus Group

The Faculty of Engineering, Computing and Mathematics is undertaking a project to develop methods for surveying employers to produce a profile of our graduates. A fundamental component of the project involves identifying the key competencies required of engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations. The study is being conducted as a Ph.D. project by Ms. Sally Male, under my supervision.

Two large-scale surveys of engineers have been conducted and a focus group will now be held to refine descriptions of key competency factors (attached) identified from the survey results. I would like to invite you to participate in the focus group. A more detailed summary of the objectives of the study and purpose of the focus group session is given in the attached documents, "Summary.pdf" and "Description of Competencies.pdf".

Light refreshments will be provided at the session, which should not last longer than 90 minutes.

Time: 5pm

Venue: Venue at The University of Western Australia, to be advised
Date: To be advised

I would be grateful if you could reply to this e-mail by 17 August, indicating whether or not you can participate. If you are interested in participating, please indicate your availability for each of the following days:

Monday August 31
Wednesday September 2
Thursday September 10

The participation of industry representatives will be essential to the success of this project. We will be most grateful if you can spare some time to join us at the focus group.

Yours sincerely,

Mark.

Professor Mark Bush

Winthrop Professor of Mechanical Engineering

The University of Western Australia,

M459, 35 Stirling Highway,
CRAWLEY, WA 6009,
Australia

Ph. 8 6488 7259

Fax: 8 6488 1075

Email: mark.bush@uwa.edu.au

Appendix XXVII. Information Sheet for Focus Group

THE UNIVERSITY OF
WESTERN AUSTRALIA

School of Mechanical Engineering

Focus Group on Key Competency Factors for Engineers

Research Project Information Sheet

I am currently supervising a Ph.D. candidate (Ms Sally Male), whose research will develop and validate an instrument for assessing the generic competencies of recent engineering graduates. A fundamental component of the project involves identifying the key competencies required of engineering graduates. As part of a continuous cycle of improvement, this information will help us to keep the course aligned with industry needs and expectations.

Two large-scale surveys of engineers have been conducted, and a focus group will now be held to refine descriptions of key competency factors identified from the survey results. You are invited to participate in the focus group. The group will include approximately 12 people. Should you choose to participate, you will receive a set of guiding questions prior to attending.

The focus group will last no longer than 90 minutes. The session will be video- and audio-recorded to allow the information from the session to be transcribed. No reference to individual participants will be made in any resulting publications, **unless you specifically indicate that you wish to be acknowledged in this way.**

If, having read this information sheet, you decide to participate, you will be asked to sign a consent form on your arrival at the focus group (sample attached for your information).

If you have any inquiries about the project, please contact me.

Chief Investigator/Principal Supervisor

Winthrop Professor Mark Bush

The University of Western Australia

M459, 35 Stirling Hwy,

Crawley, Western Australia 6009

Fax: (08) 6488 1075

Telephone: (08) 6488 7259

Email: mark.bush@uwa.edu.au

Appendix XXVIII. Consent Form for Focus Group

THE UNIVERSITY OF
WESTERN AUSTRALIA

School of Mechanical Engineering

Focus Group on Key Competency Factors for Engineers

Research Project Consent Form

I (the participant) have read the information provided and any questions I have asked have been answered to my satisfaction. I agree to participate in this activity, realising that I may withdraw at any time without reason and without prejudice.

I have been advised as to what data is being collected, what the purpose is, and what will be done with the data upon completion of the research.

I agree that research data gathered for the study may be published.

Name:

Signature:

Date:

Do you wish to be acknowledged by name in any resulting publications and/or reports?

Yes ☐

No ☐

The Human Research Ethics Committee at the University of Western Australia requires that all participants are informed that, if they have any complaint regarding the manner, in which a research project is conducted, it may be given to the researcher or, alternatively to the Secretary, Human Research Ethics Committee, Registrar's Office, University of Western Australia, 35 Stirling Highway, Crawley, WA 6009 (telephone number 6488-3703). All study participants will be provided with a copy of the Information Sheet and Consent Form for their personal records.

***Appendix XXIX. Background, Guiding Questions and
Description of Competencies, for Participants of
Focus Group***

Competencies of Engineering Graduates Project

Focus Group on Key Competency Factors for Engineers

Sally Male
September 10, 2009

The purpose of the focus group is to refine descriptions of eleven key competency factors which have been revealed during the analysis of survey results.

Background

It is planned that the key competency factor descriptions will be used in a survey instrument asking supervisors of graduates to rate the competencies of graduates as follows.

Based on the average performance of the graduate, how successfully does the graduate usually demonstrate this key competency factor?

1 extremely badly

2

3

4

5 extremely well

N/A – there is no opportunity for the graduate to demonstrate this competency

Guiding Questions

1. For each competency factor please consider the following.
 - Is each competency clear?
 - Do all of the competencies fit the factor? Would they be needed in similar types of jobs?
 - Can the clarity or accuracy of the name for the competency factor be improved?
 - Do the items comprehensively represent the factor?
2. Do the factors comprehensively represent the generic competencies required by engineers?

Key Competency Factor Descriptions to be Refined During the Focus Group

I. Communication

For example

- using effective graphical communication (e.g. drawings)
- speaking and writing fluent English
- using effective verbal communication (e.g. giving instructions, asking for information, listening)
- communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)

II. Working in Diverse Teams

For example

- interacting with people in diverse disciplines/professions/trades
- interacting with people from diverse cultures/backgrounds
- working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)

III. Self-Management

For example

- managing personal and professional development (e.g. self-directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)
- managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health)
- managing information/documents
- managing his/her communications (e.g. keeping up to date and complete, following up)
- having an action orientation (e.g. avoiding delays, maintaining a sense of urgency)

IV. Professionalism

For example:

- being loyal to his/her organization (e.g. representing it positively)
- demonstrating honesty (e.g. admitting mistakes, giving directors bad news)
- being committed to doing your best
- presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)
- being concerned for the welfare of others in one's organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution)
- acting within exemplary ethical standards

V. Creativity / Problem-Solving

For example

- thinking critically to identify potential possibilities for improvements
- sourcing/understanding/evaluating information (e.g. from co-workers /colleagues/documents/ observations)
- thinking laterally / using creativity/initiative/ingenuity
- trying new approaches/technology / capitalising on change / initiating/driving change
- solving problems (e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs)
- being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
- using a systems approach
- Using design methodology (e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating)

VI. Management/Leadership

For example

- supervising work/people
- leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)
- coordinating the work of others
- managing (e.g. projects/programs /contracts/people/strategic planning/performance/change)
- taking considered risks
- chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)
- making decisions or balancing trade-offs within time and knowledge constraints

VII. Engineering Business

For example

- applying familiarity with risk/liability/legislation/standards/codes / IP issues
- applying familiarity with the different functions in your organization and how these interrelate
- focusing on his/her organization's needs

VIII. Practical Engineering

For example

- evaluating / advocating for / improving maintainability
- evaluating / advocating for / improving manufacturability/constructability
- evaluating reliability / potential failures
- using “simultaneous engineering design and development” / “integrated product and process design” / “collaborative engineering”

IX. Innovation

For example

- engaging in entrepreneurship / innovation / identifying and commercialising opportunities
- evaluating marketing issues / applying a customer focus
- networking (i.e. building/maintaining personal/organizational networks)
- keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials
- presenting clearly and engagingly (e.g. speaking, lecturing)

X. Contextual Responsibilities

For example

- evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions
- being concerned for the welfare of the local, national and global communities
- evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)
- evaluating / advocating for / improving health and safety issues

XI. Applying Technical Theory

For example

- applying mathematics, science or technical engineering theory or working from first principles
- using 3D spatial perception or visualization (e.g. visualizing various perspectives)
- modelling/simulating/prototyping and recognising the limitations involved
- using research / experimentation techniques / scientific method

**Appendix XXX. Biographical Questionnaire for
Focus Group**

Competencies of Engineering Graduates Project
Focus Group
September 10, 2009
Biographical Questionnaire

The purpose of this questionnaire is to collect the demographic information about the participants in the focus group. Although names of participants will be acknowledged in resulting publications if requested, demographic information will not be matched to names at any time. Completion of each questionnaire item is voluntary.

Q1. Your experience (Please tick all applicable.)	
☐	HAVE WORKED WITH ENGINEERING GRADUATES (WITHIN APPROX. FIVE YEARS SINCE GRADUATION)
☐	HAVE SUPERVISED ENGINEERING GRADUATES (WITHIN APPROX. FIVE YEARS SINCE GRADUATION)
☐	HAVE SUPERVISED OR MANAGED ENGINEERS WITH MORE EXPERIENCE THAN GRADUATES

Q2. Locations in which you have worked (Please tick all applicable.)	
☐	WA
☐	AUSTRALIAN STATE OTHER THAN WA: _____
☐	COUNTRIES OTHER THAN AUS: _____

Q3. Qualifications ³ (Please circle one response per row.)		
1st Qualification	BE BSc BA BComm MBA PhD	OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech	OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)	
Country	AUSTRALIA	OTHER:
2nd Qualification	BE BSc BA BComm MA MBA PhD	OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech	OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)	
Country	AUSTRALIA	OTHER:
3rd Qualification	BE BSc BA BComm MBA PhD	OTHER:
Discipline	Chem Civil CompSci ElecCompE Mech	OTHER:
Status	COMPLETED PARTIALLY-COMPLETED COMPLETED WITH HONOURS (relevant to Bachelor degrees only)	
Country	AUSTRALIA	OTHER:

³ adapted from Turley, R.T., “Essential Competencies of Exceptional Software Engineers”, PhD Dissertation, Colorado State University, 1991, pp186

Q4. Industries in which you have experience⁴ (Please tick all applicable.)

☐	APPLIANCES AND ELECTRICALS
☐	BASIC METAL PRODUCTS
☐	CHEMICAL AND PETROLEUM
☐	COMMUNICATION INCLUDING TELSTRA
☐	CONSTRUCTION, CONTRACT, MAINTENANCE
☐	CONSULTING AND TECH SERVICES
☐	DEFENCE
☐	EDUCATION
☐	ELECTRICITY AND GAS SUPPLY
☐	FABRICATED METAL
☐	FOOD, BEVERAGE AND TOBACCO
☐	INDUSTRIAL MACHINERY
☐	MINING OR QUARRYING
☐	NON-METALLIC MINERALS
☐	OIL/GAS EXPLORATION/PRODUCTION
☐	PUBLIC ADMINISTRATION
☐	SCIENTIFIC EQUIPMENT
☐	STEEL PRODUCTION
☐	TRANSPORT AND STORAGE
☐	TRANSPORT EQUIPMENT
☐	WATER, SEWERAGE AND DRAINAGE
☐	WOOD AND PAPER PRODUCTS
☐	OTHER MANUFACTURING
☐	OTHER NON-MANUFACTURING
	OTHER: _____

⁴ Classifications adapted from:

Association of Professional Engineers, Scientists and Managers, Australia (APESMA) (2004), APESMA / Engineers Australia Professional Engineers Remuneration Survey Summary Report
Association of Professional Engineers, Scientists and Managers, Australia (APESMA) (2005), APESMA / Engineers Australia Professional Engineers Remuneration Survey Summary Report

Appendix XXXI. Opinions in Response to Guiding Question 1 in the Focus Group to Validate and Refine the Generic Engineering Competency Model

As noted in Chapter 9, suggestions to improve the generic engineering competency factors are presented by competency factor and guiding question. Any specific participant has a consistent letter as a label throughout any discussion on one topic but not throughout the appendix. Responses to guiding questions for which no problems or improvements were suggested are not presented.

1.1. Competency Factor I. Communication

The competency factor was presented to the focus group with the following competencies:

- using effective graphical communication (e.g. drawings)
- speaking and writing fluent English
- using effective verbal communication (e.g. giving instructions, asking for information, listening)
- communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)

1.1.1. Responses to Guiding Questions

Is each competency clear?

The following suggestions were received:

- replace the second item with “competency in fluent English: both spoken and written”, “not just saying ‘Gooday’”

- separate speaking English and writing English
- “using effective *spoken* communication ” rather than *verbal* communication
- change the last competency to make it a “higher level”, including writing clearly, concisely and “persuasively”, in “different styles from complex technical to non-technical”, “appropriate to various readerships”, “persuasiveness is probably only seen in 20% of graduates”
- all items should include understanding

Quotations elaborating the above points follow. Persuasiveness was demonstrated by the following example:

[Engineers need to] not only identify opportunities but be able to sell them... An engineer who can really analyse it to the nth degree but cannot sell the idea is no use. [Participant A]

An explanation of the need for different styles of writing for different readerships follows:

The other thing that is a very useful skill (I don't know how essential it is) is to be able to explain complex, specialised, technical matters to non-technical people who work in a different discipline ah an example ah persuading ah persuading the board if you need to spend five hundred thousand dollars on powerful equipment. [Participant B]

That is a subset of what I was thinking of. [Participant C]

An example explaining the need for understanding was:

You are giving a graduate instructions all of the time and you want them to understand what you are asking them to do. [Participant D]

Do the items comprehensively represent the factor?

An additional item was suggested related to using the most appropriate technology of communication, and appropriate etiquette, for each given purpose, including modern

technology available for long-distance communication and appropriate etiquette.

Participants discussed this as follows:

I feel there should be some reference to the technology. It should be - I mean it's probably a given – most graduates should be able to – they've got to understand there's lots of different ways of communicating, and there's a best at any given time, particularly if you are overseas and we've got fluent people in English here that aren't capable of communicating to people who can't speak English and there's a technology – there's a good way of doing it. It's like having too many dot points on the page – those sorts of things.
[Participant A]

It's the ability to be able to do public speaking without PowerPoint
[Participant B]

Yeah right. [Participant A]

There's also things like email etiquette which is really important and some graduates don't understand until they transgress once or twice.
[Participant C]

Not only graduates. [Participant D]

“Effective documentation” was raised when the Practical Engineering Factor was discussed:

You can have realms and realms about the programming but nothing about the assumptions.

1.2. Competency Factor II. Working in Diverse Teams

The competency factor was presented to the focus group with the following competencies:

- interacting with people in diverse disciplines/professions/trades
- interacting with people from diverse cultures/backgrounds

- working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)

1.2.1. Responses to Guiding Questions

Can the clarity or accuracy of the name for the competency factor be improved?

- “Interpersonal Team Skills” was suggested as an option. However, others liked the word “working” in the name for the competency factor.
- “Diverse” was considered redundant by one participant, because lack of diversity could be the problem that demands competency.
- “Working with Other People” was suggested.

The following conversation demonstrates the various opinions and how the group interacted:

Yeah, actually I wouldn't use the word diverse. Sometimes the problem is that everybody's the same. [Participant A]

One of the key competencies, through working with our HR people, one of the key competencies we use is “emotional intelligence”, and it covers an awful lot of ... which is the background to people being diverse.
[Participant B]

Yeah but if you're going to send this out to, ah, a whole lot of engineers.
[Participant C]

[Many laughed.]

I hear what you're saying. [Participant B]

“Emotional intelligence” is broader. It goes right up to self-actualisation.
[Participant D]

Exactly. [Participant E]

Interpersonal skills. [Participant D]

Could you just delete the word “diverse”? “Working in teams.” That says it all. [Participant A]

Perhaps interpersonal team skills could be part of the description.
[Participant C]

But working is good. [Participant A]

[Many laughed.]

But the essence of working in teams is to be able to work with other people.
Some people miss that point. [Participant D]

Do the items comprehensively represent the factor?

Additions were suggested:

- “stay informed where appropriate”
- “humility”
- working with “different levels of hierarchy”
- “sharing information where appropriate”
- “know where you fit in the team”

The constructive interaction between participants is demonstrated in the following discussion on working with different levels of hierarchy:

Perhaps an additional point there may be to cover people with different, um, with different levels in the hierarchy if you like. [Participant A]

Being able to work with others in a different level of the organization.
[Participant B]

Yeah. [Participant A]

Including client organizations. [Participant C]

Humility was raised as follows:

Something about humility which a lot of graduates don't have. When they come out they think they know everything. [Participant A]

I'd agree. [Participant B]

Something that you get by, you know, tying people to power poles and
[Participant A]

[Some laughed.]

1.3. Competency Factor III. Self-Management

The competency factor was presented to the focus group with the following competencies:

- managing personal and professional development (e.g. self-directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)
- managing self (e.g. time/priorities / quality of output / motivation/efficiency/ emotions / work-life balance/health)
- managing information/documents
- managing his/her communications (e.g. keeping up to date and complete, following up)
- having an action orientation (e.g. avoiding delays, maintaining a sense of urgency)

1.3.1. Responses to Guiding Questions

Is each competency clear?

Improvements were suggested:

- replace “action orientation” with “action and goal orientation”
- extend “maintaining a sense of urgency” with “without being personally stressed”

The following conversation elaborates:

I like that last one. It goes right to the top. “Maintaining a sense of urgency”. [Participant A]

I find, ah, lots of people don’t have that. [Participant B]

[Other discussion]

I was going to put a qualifier, “Maintaining a sense of urgency without becoming personally stressed”. [Participant C]

I like that last item too but instead of the word “action”, “having a *goal* orientation”, action supporting the goal. [Participant D]

OK. That’s to do with focus? [PhD candidate]

Is it? Have you got that somewhere? It’s not much point being active; you’ve got to get somewhere. Perhaps having an action *and* goal orientation? [Participant D]

I would strongly agree. Is that “managing self (time priorities)”?
[Participant B]

It just doesn’t say it. [Participant D]

I think one of the things that differentiates the engineering graduates from the science graduates is their output. They’re organized and quite focused in

a way that – that’s one thing that engineering seems to have pushed.

[Participant C]

And you wonder whether that’s because it attracts people who are practical

– just their professional ethics. [Participant E]

I think it’s just ‘cause their undergraduate course has just worked them so bloody hard.

[Some laughed.]

They’ve survived it so that’s goal number one. [Participant D]

[Discussion about whether this is still allowed.]

I’m glad that you’ve got work/life balance and health in there. I think that’s important. [Participant E]

Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?

It was suggested that the last competency should be the first within the factor.

Do the items comprehensively represent the factor?

Additions suggested were:

- “aspirational elements”
- “curiosity”
- “be focused and efficient”

1.4. Competency Factor IV. Professionalism

The competency factor was presented to the focus group with the following competencies:

- being loyal to his/her organization (e.g. representing it positively)

- demonstrating honesty (e.g. admitting mistakes, giving directors bad news)
- being committed to doing your best
- presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)
- being concerned for the welfare of others in one's organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution)
- acting within exemplary ethical standards

1.4.1. Responses to Guiding Questions

Is each competency clear?

The following suggestions were made:

- replace “facilitating their contribution” with “facilitating the contribution of others”
- delete “in one's organization” from the second last competency
- delete “voluntarily sharing information” from the second last competency, because this is not always appropriate
- replace “voluntarily sharing information” with “voluntarily sharing information where appropriate”

Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?

Participants discussed deleting “ensuring decisions are fair” and “facilitating their contribution” from the second last competency, because these were possibly not competencies. However, the consensus was to keep these.

A participant suggested that “sharing information” would be better in Factor II Teamwork, as “sharing information where appropriate”.

A participant suggested that “sharing information” should be replaced by a new factor in Factor VII Engineering Business, “learning what is expected (e.g. when to share information).”

Can the clarity or accuracy of the name for the competency factor be improved?

A participant suggested that the competency factor name should be “Ethics and Professionalism”, with “Ethics” first because these were considered to be more important than professionalism. However, others considered that this would inappropriately imply that professionalism did not include ethics. Opinion was divided on this. One participant felt that ethics and professionalism are different, and others felt that ethics are part of professionalism.

Do the items comprehensively represent the factor?

Additions were suggested:

- “duty of care”
- “understanding of judgements regarding business practices”
- “understanding who stakeholders are”
- “recognising conflict of interest and knowing what to do”

1.5. Competency Factor V. Creativity / Problem-Solving

The competency factor was presented to the focus group with the following competencies:

- thinking critically to identify potential possibilities for improvements
- sourcing/understanding/evaluating information (e.g. from co-workers/ colleagues/documents/ observations)
- thinking laterally / using creativity/initiative/ingenuity

- trying new approaches/technology / capitalising on change / initiating/driving change
- solving problems (e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs)
- being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
- using a systems approach
- using design methodology (e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating)

I raised two issues:

- *Using a systems approach* was rated higher by electrical engineers than others in Survey 1. Could this be due to ambiguity? This item was adapted from the graduate attributes stipulated by Engineers Australia (EA 2005b).
- The final competency item did not receive high ratings of importance in the surveys. Could this be due to the word “methodology”?

1.5.1. Responses to Guiding Questions

Is each competency clear?

The discussion revealed diverse conceptual understandings of “using a systems approach”. Participants agreed that it was an important and core competency.

Alternatives for “using a systems approach” were suggested: “using a whole of systems approach (i.e. viewing a problem in the larger context)”, or “viewing the problem in a broader context”. The understandings of a systems approach follow.

The first understanding described by a participant was about process orientation:

Some people see this as the opposite side of the coin to results oriented:
systems oriented – being proactive rather than reactive, predicting. A

systems approach tends to imply you are very process oriented.

[Participant A]

A few participants described a goal orientation:

I'm just looking through this and I'm thinking, you know, problem-solving / creativity being picking a piece of technology whatever you think is a damn good idea – I like that piece of technology – but you're not actually solving a business problem, having a bigger picture, and so that's why maybe looking down the bottom line there. [Participant B]

[Further discussion.]

Again and again we see engineers that latch onto a solution without
[Participant C]

Actually solving it [Participant D]

Thinking about stepping back to think about what the customer's expectation is. [Participant C]

It's the old solution to the wrong problem. [Participant E, the goal orientation understanding]

[Participant D nodded.]

Again [Participant C]

Developing a very elegant solution [Participant F]

That's when I think about systems engineering. I think about that - of the focus on - the focus particularly on, requirements – understanding what the requirements and expectations are. [Participant C]

So that's viewing the problem in the larger context, or is that different?
[PhD candidate]

Yes. [Participant C]

The whole of system understanding, which is about thinking of all relevant systems, was related to the goal orientation understanding. Continuing from above:

But you're using a whole of systems approach. [Participant F]

That's what we need. [Participant C]

One participant introduced models into the discussion:

A systems approach being using the expected model of doing something and finding a continuous performance improvement model applied to
[Participant G, an understanding related to modelling systems]

Finally, it was agreed that "a systems approach" was not understood consistently among the participants.

Everybody likes the idea but everybody has a different idea. I think use the word context. It would be useful to solve in context correctly.
[Participant H]

Having knowledge in more than one discipline. [Participant C]

That's - that's - systems. [Participant H]

With respect to *Using design methodology*, one participant commented,

I really like what you've packed into there but it's a bit more than creativity/ problem-solving. Design methodology – I think that's [hands wide apart indicating something big] such an important concept. - it's the whole "engineering process". This is the art. It's Stage 2 [referring to Engineers Australia competencies for chartered status]. It's designing.

Can the clarity or accuracy of the name for the competency factor be improved?

It was suggested that the competency factor name should be "Ingenuity" or "Working Smart".

Do the items comprehensively represent the factor?

Additional items were suggested:

- “a strong sense of curiosity”
- “question everything”
- “curious and questioning attitude”
- “having an interest in industry”
- “anticipating problems”, “being proactive rather than reactive”, “predicting”
- “application of models”
- “cost”, “solving problems in a cost-effective way”

Curiosity was described as follows:

There’s a difference between what is in the course and being presented with a problem, and you can either not come and find out where the problem fits in the system and if you don’t find out where it fits in the system, if you don’t find out where it fits in the system you are limited as a developing engineer. “Got that view to finding out a bit more.” That’s what I’m trying to describe.

1.6. Competency Factor VI. Management/Leadership

The competency factor was presented to the focus group with the following competencies:

- supervising work/people
- leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)
- coordinating the work of others
- managing (e.g. projects/programs /contracts/people/strategic planning/performance/change)
- taking considered risks

- chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)
- making decisions or balancing trade-offs within time and knowledge constraints

I noted that *Negotiating / asserting/defending approaches/needs* weakly fitted this factor statistically, but I had removed it because it did not fit as well as other competencies and I considered that the remaining competencies require negotiation.

1.6.1. Responses to Guiding Questions

Is each competency clear?

Participants suggested that “taking considered risks” should be replaced with “managing risks” or “actively managing risks”.

Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?

A participant commented that *leading* was not really a graduate level competency. It could be “picked up in the workplace”.

Can the clarity or accuracy of the name for the competency factor be improved?

“Management and Leadership” was suggested.

Do the items comprehensively represent the factor?

An additional competency was suggested: “understanding roles and responsibilities of self and others”.

In response to the question about whether *negotiation* was encompassed by the existing items, the following comments were made:

A lot of these things seem to be worded so they are very internally focused. Negotiation is quite externally focused. You still need to show management and leadership externally. [Participant A]

Negotiation is also covered in number two [*leading*]. [Participant B]

[Another participant nodded.]

1.7. Competency Factor VII. Engineering Business

The competency factor was presented to the focus group with the following competencies:

- applying familiarity with risk/liability/legislation/standards/codes / IP issues
- applying familiarity with the different functions in your organization and how these interrelate
- focusing on his/her organization's needs

I explained that despite being reflected by only three items, the presence of this factor was robust to various factor analysis extraction and rotation methods, that senior engineers in the second survey commented that more business items were required, and therefore participants were encouraged to suggest more items that might reflect the factor.

1.7.1. Responses to Guiding Questions

Can the clarity or accuracy of the name for the competency factor be improved?

“Engineering Processes”, “Commercial Awareness”, and “Business Skills” were suggested by participants but the group settled on “Engineering Business”.

Do the items comprehensively represent the factor?

Suggestions were:

- “financial understanding (IRR [internal rate of return], cash-flow, etc)” “NPV”
[net present value], “costing: must be able to read a balance sheet”
- “commercial awareness”, “commercial skills”

- “business case preparation”, “project viability (prefeasibility, feasibility studies, etc.)”
- “profitability”
- “networking”
- “tendering, procurement”
- “marketing techniques”, “understand basic marketing techniques”
- “understanding your niche – understanding what makes your business successful”

The final of these was considered very important.

Examples explaining the need for marketing and for commercial awareness follow:

You want your graduate when they’re out there doing their job to be able to mention some of the other services that you might be able to provide.

[Participant A]

People in engineering need to ask the value of the proposal. Is it worth the bottom line to do it, put something out, or keep something in?

[Participant B]

1.8. Competency Factor VIII. Practical Engineering

The competency factor was presented to the focus group with the following competencies:

- evaluating / advocating for / improving maintainability
- evaluating / advocating for / improving manufacturability/constructability
- evaluating reliability / potential failures
- using “simultaneous engineering design and development” / “integrated product and process design” / “collaborative engineering”

I explained that *practical* had fitted the factor statistically but had been removed to improve discriminant validity and that earlier stages of the Project has raised concern about the clarity of the final item.

1.8.1. Guiding Questions

Is each competency clear?

Suggestions were:

- to delete the last item
- to replace the last item with, “using engineering process frameworks (pre-feasibility/feasibility/design/detailing etc)” or “using an appropriate method for engineering process” which was seen as linked to the “engineering process” *design* in Factor V Creativity / Problem-Solving
- to combine the first two items

With respect to the last item in the presented factor:

If you look at that, that is saying that there are different examples of engineering process and it is the recognition that they exist and the ability to use them and accept them and not saying, “Sod that. I’m doing it my own way, so there.”

Do the items comprehensively represent the factor?

In addition to including the *practical* item, participants suggested:

- “react to intuitive doubt”, “having a checking ethos”, “does the result make sense?”
- being familiar with documentation
- “understanding scope”
- “simplicity”

Explanation follows:

To have a sense of what’s right, you know, a feel for when you get, when you do the calculations and you get the numbers – does that make sense?
[Participant A]

Is that the intuitive doubt? That’s what I thought. [Participant B]

It’s almost an experience thing, isn’t it? [Participant C]

I mean, the number of times I've seen people present me with stuff that's been done using the remotest whiz bang software with a lot of graphs and numbers and figures and the results but I say, "Yeah but have you thought about that. Does that make sense?" "Oh". [Participant A]

[other discussion]

Checking and accepting renewals. [Participant D]

That's the understanding that faults do occur. [Participant E]

1.9. Competency Factor IX. Innovation

The competency factor was presented to the focus group with the following competencies:

- engaging in entrepreneurship / innovation / identifying and commercialising opportunities
- evaluating marketing issues / applying a customer focus
- networking (i.e. building/maintaining personal/organizational networks)
- keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials
- presenting clearly and engagingly (e.g. speaking, lecturing)

1.9.1. Guiding Questions

Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?

A participant commented that *networking* could not fit under an Innovation factor. It was suggested that if the factor was removed then *networking* could be under Factor III Self-Management, *keeping up to date* under Factor IV Professionalism, and *presenting* under Factor I Communication.

Can the clarity or accuracy of the name for the competency factor be improved?

Participants suggested “External Engagement”, “Commercialising Opportunities Where Appropriate”, or “Entrepreneurship”.

Other comments were:

- “Seems to be business skills to me.”
- “Innovation is more, to me it’s more, creativity.”

The following comment is relevant to engineers’ identities:

If you call it entrepreneurship, there’s going to be a lot of engineers saying,
“Well that’s why I did engineering, because I’m not an entrepreneur.”

[Participant A]

Except a lot of [PhD candidate]

Yeah in the end they have to be entrepreneurial. Quite right. [Participant A]

1.10. Competency Factor X. Contextual Responsibilities

The competency factor was presented to the focus group with the following competencies:

- evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions
- being concerned for the welfare of the local, national and global communities
- evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)
- evaluating / advocating for / improving health and safety issues

1.10.1. Guiding Questions

Can the clarity or accuracy of the name for the competency factor be improved?

Not all considered the title to be satisfactory. “Sustainability”, “Duty of Care” and “Professional Responsibility” were suggested. There was strong support for “Duty of Care” and the participants settled on “Professional Responsibility”.

1.11. Competency Factor XI. Applying Technical Theory

The competency factor was presented to the focus group with the following competencies:

- applying mathematics, science or technical engineering theory or working from first principles
- using 3D spatial perception or visualization (e.g. visualizing various perspectives)
- modelling/simulating/prototyping and recognising the limitations involved
- using research / experimentation techniques / scientific method

1.11.1. Guiding Questions

Do all of the competencies fit the factor? i.e. Would they be needed in similar types of jobs?

The second item, “3D spatial perception or visualization”, was questioned.

Can the clarity or accuracy of the name for the competency factor be improved?

Participants energetically supported the factor:

I like this one because I’m continuously disappointed by graduates who’ve forgotten their basic physics and chemistry from school. [Participant A]

Yeah. [Participant B]

[Many laughed.]

I also [Participant C]

I agree. [Participant D]

[Participant A described an example and many laughed throughout. The example ended as follows.]

and if you compress it, its temperature is going to go up you know. Well you know pressure is proportional to the height of the fluid. How hard is that? They've got no idea. I get excited about it. [Participant A]

Do the items comprehensively represent the factor?

Suggested additions:

“continuous life-long learning”, “continuing professional development”

Appendix XXXII. Investigation Of Gender Typing Of Engineering Jobs Among Engineers

This appendix reports an investigation of gender typing, using competency ratings from Surveys 1 and 2. The appendix is adapted from a journal paper (Male *et al.* 2009c) on an investigation of gender typing among senior male engineers, and a conference paper on the coding of the stereotypical gender of the competencies (Male *et al.* 2009b), both written by the PhD candidate.

Abstract

This study takes the view that engineering educators need to develop the competencies required for engineering work, and attract and retain students from diverse backgrounds. The possibility is investigated that the perceived importance of competencies is subconsciously influenced by gendered assumptions, and as a consequence, that this could lower the status given to stereotypically feminine competencies. In two surveys, engineers rated the importance of 64 competencies. The ratings made by the first sample were assumed to be relatively unaffected by gender typing. However, engineers in the second sample were asked to think of a typical engineering job, and therefore their responses were more likely to have been affected by gender typing. Results confirmed there are stereotypically feminine competencies that are important to engineering, and suggested that senior male engineers in the study gender typed engineering jobs, consequently under-rating the importance of some stereotypically feminine competencies recently added to engineering curricula.

1. Introduction

The work of engineers contributes to economic success, quality of life and protection of environments. For these purposes, engineering education must attract and retain proficient students, and develop in students the competencies required for engineering work. This study investigates the possibility that perceived importance of competencies is subconsciously influenced by the gendered nature of engineering, and as a

consequence, that low status is subconsciously and erroneously given to stereotypically feminine competencies. Such bias would undermine engineering education by marginalising important competencies, female students and female engineers. This would reduce engineering education's ability to develop all required competencies and to recruit and retain proficient students of both genders.

2. Theoretical Framework

2.1. Gender Typing

The term, “think manager, think male” was used in studies that determined that managerial positions are sex role stereotyped (Schein 1973, Schein 1975, Schein and Marilyn J. 1993, Schein *et al.* 1996). These studies support the theory that people use preconceived prototypes of successful practitioners to guide their expectations of men and women and the attributes of successful practitioners. Results indicated that characteristics that participants thought of as desirable for managers, more closely resembled characteristics that participants expected in a man than those expected in a woman. This was evidence of sex role stereotyping among the participants, as it linked to assumptions based on the biological characteristic, sex. In contrast, the current study investigated *gender* typing of engineering jobs. This study asked about competencies for engineering jobs and did not ask participants about expected characteristics of men and women.

2.2. Gendered Organizations

Since Schein's early work, Acker (1990) revealed the concept of gendered organizations. These reinforce a gendered culture and hierarchy by normalising the needs, practises and features of the dominant gender. The phenomenon observed by

Schein, and the theory of gendered organizations, support each other and provide the theoretical framework to this study.

2.3. Gendered Cultures and Gender Typing in Engineering

Studies in engineering contexts provide examples in engineering of gendered cultures and the phenomena described by Schein and Acker (Bagihole *et al.* 2008). Evetts (1998) described the experiences of female engineers in a gendered engineering organization in the UK. Fletcher's book *Disappearing acts: gender, power and relational practice at work* (1999) revealed a gendered organization in an engineering design firm in the USA. She observed active hiding of important stereotypically feminine competencies such as teamwork. Faulkner, based on research in the USA and the UK, identified an "in/visibility paradox" for female engineers, being both visible due to their sex and invisible as engineers due to gendered workplace cultures (Faulkner 2006, p.11). Gill, Sharp, Mills, and Franzway (2008) investigated workplace culture in engineering organizations across Australia. Interviews with female engineers suggested a gendered culture and gender typing of engineers:

[Female engineers'] stories of work included incidents wherein they were continually reminded of their femaleness as an impediment to being seen as a competent colleague (Gill *et al.* 2008, p.395).

In the education context, Godfrey's PhD project (2003) found indications the New Zealand engineering school that she studied was masculine gendered. Tonso (2007), in her participatory research within project-based learning groups in a USA university, observed a gendered treatment of students by both academics and students. Godfroy-Genin and Pinault (2006), as part of the WomEng project, collected qualitative and quantitative data revealing that, although there is variation across countries, among

female and male engineering students in Europe images of masculinity fitted images of masculine engineers better than images of femininity fitted images of masculine engineers. Such studies instil confidence that engineering and engineering education are gendered, and alerted me to investigate the influence of this on competency development in engineering education.

3. Rationale

During the last three decades engineering curricula have broadened from the technical and analytical focus previously honed. Awareness of engineering's relationship with societies and environments, understanding of ethics, communication, teamwork, and learning skills were gradually introduced. Program accreditation criteria, pedagogies, assessments, and learning environments have changed. The theoretical framework of this study suggests that a gendered culture within engineering, specifically manifesting as gender typing, could be undermining these changes to engineering education.

3.1. Background

3.1.1. Previous Emphasis on Technical Content

From the 1960s to the 1980s engineering education in western countries focused on technical content: mathematics, pure science and engineering science. Taking an historical perspective, Ferguson (2006b) compared the development of engineering education in the UK, USA, France, Germany and Australia. Mathematics, science and technical engineering theory and practice, formed the core of original university engineering courses on continental Europe in the 18th century, approximately a century later in the USA and eventually in the UK and Australia when engineering was finally taught in universities in these places. However, a feature that has changed since World War II has been the shift from teachers with experience as practising engineers, and

programs including creative design, to academics with a research and analytical focus (Prados 1998, Ferguson 2006a).

Taking a feminist perspective, work such as Hacker's (1981) study of engineering found a culture in which masculinity dominated, and was developed in students during their engineering education. This was a culture that gave status to science and technology and control, and required that engineers be separate from things to do with the body, nature, serving and uncertainties. This was an explanation for the lack of non-technical content in engineering curricula.

Feminist understanding was one of many drivers for changes to engineering education that were designed to improve recruitment and retention of female engineering students. Increased opportunities for collaboration, consideration of context, problem-based and project-based learning, and societal and environmental context were recommended as ways of making engineering education more appealing to women (Moxham and Roberts 1995). These ideas continue to be justified. Higher percentages of women have been attracted to interdisciplinary engineering programs than traditional programs (Daudt and Salgado 2005). Part of the WomEng Project in Europe surveyed engineering students. Interdisciplinary subjects, more discussion and projects and fewer lectures, and more practical work were proposed changes that were all popular with the female students (Sagebiel and Dahmen 2006).

3.1.2. Importance of Non-technical Competencies

In recent decades, the development of generic competencies beyond technical knowledge and skills has been stipulated in outcomes for accreditation of engineering courses in many countries (EA 2005b, ABET 2008, European Network for Accreditation of Engineering Education 2008, Engineering Council 2010). These changes have been supported by research results. Major studies in Europe and the USA have confirmed the need for engineering graduates to have non-technical competencies,

especially communication and teamwork (Meier *et al.* 2000, Bodmer *et al.* 2002, Brumm *et al.* 2006, Spinks *et al.* 2006). These results are consistent with those of small-sample Australian surveys (Nguyen 1998, Scott and Yates 2002, Ferguson 2006a). Newport and Elm's (1997) New Zealand study on qualities of effective engineers found that interpersonal capabilities formed one of three main groups of qualities that correlated with effectiveness. "Significantly, academic achievement showed virtually no correlation with engineering effectiveness." (Newport and Elms 1997, p.330)

3.2. Problems that Could Arise from Engineers

Gender Typing Engineering Jobs

Despite studies concluding that non-technical competencies are important, and stipulation of development of non-technical competencies in program accreditation criteria, not all academics and students have embraced development of non-technical competencies (Florman 1997, Green 2001). One reason could be that engineers gender type engineering jobs, and the relatively recently introduced competencies are stereotypically feminine.

Possible implications of gender typing for engineering education are numerous. If engineers do gender type engineering jobs, then this could bias the development of engineering curricula, and engineering education learning environments. The main concern investigated by this study is that gender typing could lead to important stereotypically feminine competencies being seen as less important than they are, and therefore not being taught and learnt seriously within engineering programs. Conversely stereotypically masculine competencies could be over-emphasised. Many other implications are raised in the discussion section.

4. Research Questions

This study asked the following:

- Do engineers gender type engineering jobs?
- Specifically, are there stereotypically feminine competencies that are important to engineering jobs but affected by gender typing among engineers?

5. Methodology

As in the work by Schein and her colleagues, surveys were used to obtain quantitative measures of effects across large samples. Much literature exists from which it was possible to develop a survey without first using qualitative methods to identify competency items.

Schein surveyed managers and management students. In this study, engineers, rather than students, were surveyed for two reasons. Engineers teach engineering, and thereby influence engineering education, which reinforces its culture (Ihsen 2005). Engineers are also frequently consulted as stakeholders of engineering education.

This study focused on competencies required by established engineers, that is, with five to twenty years' experience since graduating from an engineering degree of at least four years. These were expected to be sufficiently experienced to know which competencies were most important, but not yet to have moved into later phases of their careers, requiring different competencies.

To collect opinions that included influence of any gender typing, and others that were less biased by gender typing, data were used from two surveys. In the first survey, 300 established engineers rated the competencies for importance to their own jobs. In the second survey, 250 senior engineers, who had managed or supervised established engineers, each rated the competencies for importance to a typical job performed by an established engineer. The ratings made by the first sample were considered to be

relatively free from gender typing because, unlike Schein's surveys, each participant rated his or her own actual job rather than that of an imagined person. However, the second sample's ratings were more likely to be biased by gender typing because the participants thought of a typical job, and hence generalised. It was important to investigate gender typing among senior engineers because these people are often in managerial and leadership positions where they can influence decisions and culture.

Schein asked survey participants in three groups to imagine meeting a woman, a man, or a successful manager, and rate the characteristics they would expect that person to have. This required three large samples. Instead, in this study a separate reference group was used to identify the competencies as stereotypically feminine, masculine or androgynous.

There was a lower percentage of women in Survey 2 than Survey 1. This was consistent with the distribution of female engineers among responsibility levels in Australia (APESMA 2007). Therefore, any observed gender typing arising from this difference between demographics would have been likely to reflect experiences within engineering cultures. As expected based on literature on the gendered culture in engineering education, there were few significant differences between the perceptions of importance made by men and women in Survey 1 (Male *et al.* 2007). However, to avoid exaggeration of observed gender typing due to the difference between female participation in the surveys, female responses were removed. I therefore investigated gender typing among senior male engineers.

6. Method

6.1. Surveys

A list of 64 competencies, expected to be important to engineering work, was developed based on literature on engineering education, higher education and key competencies.

6.1.1. Survey 1

In the first survey, established engineers with five to twenty years' experience, rated each competency by answering the question "How important is each of the following to doing your job well?" using a five-point rating scale (1 = *not needed*; 5 = *critical*).

The 2542 male and female graduates, who had completed bachelor of engineering degrees from 1985 to 2001 at UWA, were invited to participate. Calls for participants were also made through industry contacts, the local division and women in engineering committees of Engineers Australia, the local section of the Institute of Electrical and Electronic Engineers, and the University's engineering graduates' newsletter. Usable responses were received from 300 engineers, 245 of whom were male.

6.1.2. Survey 2

Participants in the second survey were senior engineers experienced in managing, supervising or directing engineering teams that had included established engineers. Participants were asked to, "think of a specific typical job performed by a graduate engineer with five to twenty years' experience, in the main organization in which you are experienced... How important is each of the following for an engineer to do the typical job well?" The response scale was as in Survey 1.

Letters to 1273 male and female engineering graduates, from suitable cohorts at UWA, invited participation. Volunteers were recruited by email from the Project Management Forum and the University's industry advisory groups. Usable responses were received from 250 engineers, 246 of whom were male.

6.1.3. Demographics

The majority of the participants were working in Australia (Table 32). Most had gained their undergraduate engineering qualification in Australia and a diversity of engineering disciplines was represented. Limitations were that many of the participants were graduates of one university and many were in one State.

Table 32. Demographics of male participants in Surveys 1 and 2

<i>Demographic variable and values</i>	<i>Survey 1</i>		<i>Survey 2</i>	
	<i>n</i>	<i>%</i>	<i>n</i>	<i>%</i>
<i>Location where participant worked¹ / mainly worked²</i>				
Western Australia	185	75.5	201	81.7
Australia and outside Western Australia	37	15.1	32	13.0
Outside Australia	23	9.4	11	4.5
<i>University that awarded participant's undergraduate engineering qualification (if applicable²)</i>				
UWA	180	73.5	225	92.2
not UWA	65	26.5	19	7.8
<i>Engineering discipline in which participant was qualified¹ / mainly experienced²</i>				
civil/structural/environmental/geotechnical/mining	76	31.1	109	44.9
computer systems/electrical/electronic/communications/software/IT	79	32.4	79	32.5
mechanical/aeronautical/materials/mechatronics/metallurgical/naval architecture/chemical	89	36.5	55	22.6

Notes:

¹In Survey 1

²In Survey 2

6.2. Gender Coding of the Competencies

Members of a reference group of seven people, with academic experience that gave them insights into gender issues, were asked to “code the following [64 competencies] using stereotypes among professionals in Australia”. The group included five women and two men, from disciplines including social sciences, management and engineering. Ratings were made by marking a 100mm line to indicate a rating from *very feminine* to *very masculine*, with *androgynous* at the centre point. These were coded (-50 = *very feminine*; 0 = *androgynous*; 50 = *very masculine*). Competencies with 95%

confidence intervals that excluded 0 were coded as either stereotypically feminine or masculine, and all others as androgynous.

7. Analysis and Results

The results of the coding of the stereotypical gender for each competency are presented in Figure 61 and Figure 62.

Figure 61. Generic engineering competencies with masculine mean ratings for stereotypical gender as rated by the reference group (N = 7)

Note: Full names for the competencies are listed in Table 17.

Figure 62. Generic engineering competencies with feminine mean ratings for stereotypical gender as rated by the reference group (N = 7)

Note: Full names for the competencies are listed in Table 17.

A multivariate analysis of variance (MANOVA) was performed to compare male engineers' ratings, of importance to each stereotypically gendered competency, across the two surveys. Because the number of missing importance ratings for competencies

was small, missing ratings were imputed for analysis purposes. The maximum number of competency ratings missed by any one person was four. The maximum number of ratings missed for any one competency across both surveys was six. The number of competency ratings missed among all 491 male participants' ratings for the 64 competencies was 70 (0.22%). Normality assumptions were not all satisfied. Normalisation was undertaken to address this problem. However, as sizes of the samples were both large and almost equal, the violation of normality was not a problem. Based on Pillai's criterion, the MANOVA was significant, Pillai's Trace = 0.28, $F(29,461) = 6.08, p < 0.001$. There were significant differences across the two surveys in 14 of the 29 stereotypically gendered competencies ($p < 0.05$) (Figure 63). Ten of these were stereotypically feminine (Table 33).

Figure 63. Competencies that were identified as stereotypically masculine or feminine, and received significantly different ratings of importance across men's responses in Survey 1 ($N = 245$) and Survey 2 ($N = 246$)

Note: Eight stereotypically masculine and seven stereotypically feminine competencies were not rated significantly differently across the surveys and are not shown.

Table 33. Stereotypically feminine competencies that were rated significantly differently by the male engineers in Surveys 1 and 2

<i>Competency name</i>	<i>Competency as identified in the surveys</i>
Ethics	Acting within exemplary ethical standards
Promoting diversity	Actively promoting diversity within your organization
Loyalty	Being loyal to your organization (e.g. representing it positively)
Safety	Evaluating / advocating for / improving health and safety issues
Verbal comm.	Using effective verbal communication (e.g. giving instructions, asking for information, listening)
Self-management	Managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health)
Flexibility	Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems
Managing comm.	Managing own communications (e.g. keeping up to date and complete, following up)
English	Speaking and writing fluent English
Diversity skills	Interacting with people from diverse cultures/backgrounds

Note: Competencies are ranked by how much higher the competency was rated on average by Survey 2 (which required generalisation) than by Survey 1 (without generalisation).

Of the 29 stereotypically gendered competencies, six stereotypically feminine competencies and no stereotypically masculine competencies received a lower rating from the senior male engineers, who were required to generalise, than from the established male engineers, who rated importance to their own jobs (Table 34). This result represents a relationship within the stereotypically gendered competencies. In particular, the stereotypical gender of the competencies was related to the proportion of the competencies rated significantly lower in Survey 2 than in Survey 1. Combined with the theoretical framework for this study, the result for stereotypically feminine competencies is consistent with gender typing among the senior male engineers who participated in Survey 2.

Table 34. Distribution of stereotypically gendered competencies rated significantly differently by male engineers across Surveys 1 and 2, by stereotypical gender of the competencies

<i>Stereotypical gender of competencies</i>	<i>Number of competencies with no significant difference in ratings between the two surveys</i>	<i>Number of competencies with a significantly higher rating of importance in Survey 1 than in Survey 2</i>	<i>Number of competencies with a significantly higher rating of importance in Survey 2 than in Survey 1</i>
Feminine	7	6	4
Masculine	8	0	4

Note: Participants in Survey 1 rated competencies on importance to their own jobs. Participants in Survey 2 rated competencies on importance to a typical job within their area of expertise.

Although there were significant differences between the surveys, all competencies received mean ratings above 2.1 on the scale of importance (1 = *not needed*; 5 = *critical*) and the maximum difference between the mean ratings across the two surveys for any one competency was 0.46. This difference will not affect whether competencies are included in engineering curricula. Rather, it could influence the relative status of competencies within engineering learning environments. Figure 64 shows the stereotypically feminine competencies that have significantly different ratings of importance across the surveys.

Figure 64. Mean competency ratings for stereotypically feminine competencies that were rated significantly differently by male engineers across the two surveys, Survey 2 ($N = 246$) which required generalisation and Survey 1 ($N = 245$) which did not

Note: Full names for these competencies are listed in Table 33.

These results support three main conclusions. First, stereotypically feminine competencies, such as communication, are important (Figure 64). Second, the data suggest that gender typing of engineering jobs was present among the senior male engineers in Survey 2 (Table 34, Figure 63). Finally, this gender typing weakened the status of feminine competencies including communication, self-management, flexibility, and interacting with people from diverse cultures and backgrounds (Figure 64). These are some of the competencies added to curricula in recent decades, and this result could partly explain the difficulties experienced with their inclusion.

8. Discussion

8.1. Significance

This study provides the first quantitative results directly revealing gender typing of engineering jobs among senior engineers.

As discussed, there have been large-scale surveys, in the USA and Europe, on competencies required by engineers. However, these did not investigate the presence of gender typing. This study is the first large-scale survey of its kind in Australia, and revealed that both, stereotypically feminine competencies are important to engineering work, and senior engineers gender typed engineering.

8.2. Implications

The results of this study were consistent with subconscious gender typing of engineering jobs among engineers. An important possible implication is that the learning of stereotypically feminine competencies could be undermined by staff and consequently students due to gender typing and an associated culture that gives stereotypically feminine competencies low status.

Women and students assumed to be stereotypically feminine could be overlooked for opportunities as observed by Tonso (2007). Students could face conflicting identities between their gender and engineering, as observed by Jolly (1996), Godfrey (2003) and Du (2006) .

A major implication for programs designed to improve numbers of women graduating in engineering, is that such programs must overcome gender typing. Programs to increase participation of women in engineering have moved from an original focus on women to an understanding of the need to consider structural factors (Cronin and Roger 1999). The most successful programs have adapted the institutional structure rather than individuals (Fox *et al.* 2009).

Identity conflict arising from the complex nature of engineering work and lack of recognition of social components has been observed in engineering workplaces (Faulkner 2007). As raised by Eveline (1994), in gendered structures, the disadvantage of women, is also an advantage for men. This advantage is not usually discussed because it is hidden by the normalisation of masculine traits in gendered cultures. Just as gender typing disadvantages women, it advantages men, because they are automatically more likely to be considered for opportunities and because they are less likely than women to experience identity conflict, related to gender. Robinson and McIlwee (1989) measured gender gaps in status and pay in engineering. These persist (APESMA 2007). Robinson and McIlwee attributed the gaps to a difference between women's and men's confidence and assertiveness, and even concluded that among electrical engineers in a high-tech organization women's confidence and assertiveness were damaged. Theory of gendered organizations and this study's evidence of gender typing in engineering allow additional understanding of McIlwee and Robinson's data. Gender typing would contribute to both, allocation of women to the lower status more stereotypically feminine roles given to engineers, and biased assumptions about women's competencies.

8.3. Limitations

Schein compared sex role stereotypes among men and women. Stereotypes among women were not investigated in this study, because there were insufficient women among the senior engineers. Surveys have indicated that female managers (Brenner *et al.* 1989) and female management students (Schein *et al.* 1989) in the USA no longer think manager, think male.

8.4. Recommendations for Engineering Education

Implications for the improvement of engineering education are related to curriculum planning, teaching, assessment, and staff and students' awareness. Teaching and assessment methods must be designed such that stereotypically feminine competencies are not accidentally marginalised. Staff and students must be made aware of the potential for engineers to gender type so that they can recognise, avoid, and counter this in themselves and others.

9. Conclusions

This study reveals evidence of gender typing of engineering jobs among engineers. Although this is not likely to cause omissions in engineering curricula, it is likely to undermine the development of stereotypically feminine competencies in engineering education.

10. Acknowledgements

I am sincerely grateful to the gender coding reference group members for their time and expertise: Jennifer de Vries, David Dowling, Malcolm Fialho, Susan Harwood, Lesley Jolly, Linley Lord and Julie Mills.

References

The references for this appendix are included with the references for the thesis.

Appendix XXXIII. Review of Literature on Generic Engineering Competencies

This appendix is based on a paper written by the PhD candidate (Male in press).

Abstract

This review takes the view that engineering educators have a responsibility to prepare graduates for engineering work and careers. Literature reveals gaps between competencies required for engineering work and those developed in engineering education. Generic competencies feature in these competency gaps. Literature claims that improving the development of generic competencies in engineering graduates has met barriers. One identified problem is a low status of generic competencies in engineering education. The review focuses on competencies that are required by professional engineers across all engineering disciplines, in Australia, Europe, New Zealand and the USA. The literature reveals that a helpful approach to improve generic competencies will be for engineering educators to focus on developing “generic engineering competencies” rather than separate generic competencies and engineering competencies.

1. Introduction

Multiple studies have identified generic competencies among gaps between competencies developed during engineering education and those required for engineering work. This appendix reviews related literature in order to understand the problem and how it could be approached. Motivation came from a project initiated by the engineering Industry Advisory Board at UWA, to close the loop in the continuous improvement of engineering education by profiling the competencies of graduates (Male and Chapman 2005).

This review takes the view that university engineering educators have a responsibility to society and to engineering students to develop competencies required for engineering

work. The review focuses on competencies that are required by professional engineers across all engineering disciplines, in Australia, Europe, New Zealand and the USA.

Notes on terminology are followed by the review of literature and a recommendation based on the literature.

1.1. Terminology

Confusion arises from multiple concepts of “competencies” and “generic competencies” and multiple related terms such as “generic attributes”, “generic skills” and “employment skills”. Lists, studies and applications understand similar yet varied constructs (Billing 2003). The scope of this review is not restricted to any one conceptual understanding.

In this appendix, “generic” refers to items that are important to graduates across all disciplines including engineering, and “generic engineering” refers to items that are important to engineering graduates across all engineering disciplines.

2. Competency Gaps in Engineering Graduates

Many authors have discussed influences of the changing professional context of engineering on demands of engineers and engineering education. Changes have included a movement of engineering work from in-house to consultancies, globalisation, rapid technological change and development of technical specialisations, an increasingly scrutinising society, and increased concern for environmental issues (Beder 1998, Green 2001, Mills 2002, National Academy of Engineering 2004, Becker 2006, Ferguson 2006b, Ravesteijn *et al.* 2006, Galloway 2007). These changes contribute to gaps between competencies developed during engineering education and competencies required for engineering work.

Persistent gaps related to the nature of engineering education are present in the literature. Shuman *et al.* (2005) discussed recurring calls, since more than a century ago,

for non-technical content such as communication skills and disciplines from the humanities to be taught to engineering students in the USA. Grinter (1955) highlighted a need for development of better communication skills.

More recently, gaps in communication, leadership and social skills were highlighted in the SPINE study (Bodmer *et al.* 2002), and many surveys and reviews of engineering education have found the largest competency gaps in similar areas (Williams 1988b, Connelly and Middleton 1996, Johnson 1996a, Bons and McLay 2003, WCEC 2004, Ashman *et al.* 2008, Nair *et al.* 2009). The largest capability gap as identified by Scott and Yates (2002) was emotional intelligence.

Promisingly, the most recent Australian review of engineering education noted improved oral communication and teamwork, although gaps in written communication remained (Johnston *et al.* 2008). Similarly employers' ratings indicated relative satisfaction with teamwork skills of graduates in the study by Spinks *et al.* (2006).

A cluster of literature, especially from around the time when outcomes were being introduced in engineering education, has discussed concerns about the focus of engineering education on theory and analysis at the expense of creativity, problem-solving, innovation, design, ethics, reflection and complex systems, as required for engineering practice (Holt and Solomon 1996, Lee and Taylor 1996b, Lee and Taylor 1996a, Beder 1998). Schön's study of engineering design from a philosopher's perspective raised similar issues (Schön 1983, Waks 2001). Comments received in the recent review of engineering education in Australia also support the concern (Johnston *et al.* 2008, p.69).

In the most recent decade, survey results have indicated employer dissatisfaction with engineering graduates' practical application of theory, and business skills (WCEC 2004, Spinks *et al.* 2006). These were highlighted as gaps by graduates in my survey (Male *et al.* 2010a) and employers in the most recent Australian review (Johnston *et al.* 2008).

Management and business items were found to be among competencies with the highest gaps based on graduates' ratings in an international survey of chemical engineers by the World Chemical Engineering Council (WCEC 2004). Meier *et al.*'s (2000) results indicated the highest non-technical competency gaps in *loyalty and commitment to the organization* and *customer expectations and satisfactions*. However, I found indicators of improvement in engineering business skills of graduates over recent decades (Male *et al.* 2010a).

The most recent review in Australia (Johnston *et al.* 2008), noted industry comments on poor fundamental science and engineering knowledge. This opinion is new in the literature. The most frequent concerns in the literature feature generic competencies.

3. Alignment between Engineering Education and Engineering Work

Although universities have additional purposes, few students would study engineering without expecting their education to help them prepare for engineering work.

Universities have a responsibility to respect the trust students and societies place in them to do this, as is recognised by program accreditation. However, alignment between engineering education and work has been questioned by several studies, outlined below.

In the UK, Briggs (1985) and Harvey and Lemon (1994) and, in the USA, Lee (1986) found no significant relationship between academic grades and job performance. Newport and Elms (1997) in New Zealand, found that *mental agility*, *enterprise* and *interpersonal capabilities* correlated with effectiveness. "Significantly, academic achievement showed virtually no correlation with engineering effectiveness" (p.330).

Relatively recent qualitative research in Sweden investigated the transition from study to work (Dahlgren *et al.* 2006). A finding was that mechanical engineering education resembled a rite of passage, and there was discontinuity between course content and

engineering work. Educational anthropologist, and engineer, Tonso (2007), conducted participatory research in the USA, and observed that students were able to gain high marks without demonstrating competencies required for engineering practice, and vice versa.

4. Competencies Required by Engineers

Taking the view that engineering education should be aligned with engineering work, I now consider conclusions of literature stipulating engineering education outcomes, and literature on engineering work. Elkin (1990, p.24) described “initial competencies” as the minimum competencies for a job, and “developmental competencies” for developing within a job and perhaps into a higher level job. Anderson (J.L. Anderson in Bodmer *et al.* 2002, p.11) stated “The challenge of engineering education is to simultaneously prepare students for their first job and their career 25 years later.” This suggests that engineering education must provide initial competencies for engineering work, and developmental competencies for careers.

4.1. Stipulated Outcomes in Accreditation Criteria for Engineering Education Programs

Items with both generic and generic engineering aspects are included among engineering education outcomes stipulated in Australia, Europe, New Zealand, the USA and internationally (Maillardet 2004, EA 2005a, EA 2005b, Quality Assurance Agency for Higher Education 2006, ABET 2008, European Network for Accreditation of Engineering Education 2008, Institution of Professional Engineers New Zealand 2009, International Engineering Alliance 2009a, Engineering Council 2010).

As an example, the USA-based Accreditation Board for Engineering and Technology (ABET) criteria include eleven program outcomes. Approximately half include both generic and generic engineering aspects, and half are purely generic engineering items:

- (a) an ability to apply knowledge of mathematics, science, and engineering
 - (b) an ability to design and conduct experiments, as well as to analyze and interpret data
 - (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
 - (d) an ability to function on multidisciplinary teams
 - (e) an ability to identify, formulate, and solve engineering problems
 - (f) an understanding of professional and ethical responsibility
 - (g) an ability to communicate effectively
 - (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
 - (i) a recognition of the need for, and an ability to engage in life-long learning
 - (j) a knowledge of contemporary issues
 - (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- (ABET 2008, p.2)

An alternative structure, which partly separates generic items from generic engineering items, appears in the European-stipulated outcomes. These are:

- Knowledge and Understanding
- Engineering Analysis
- Engineering Design
- Investigations
- Engineering Practice
- Transferable Skills (European Network for Accreditation of Engineering Education 2008, p.4)

Of these, only *Transferable Skills* is generic. *Transferable Skills* encompasses the non-technical ABET outcomes. Even despite this, each of the other European outcomes is not purely engineering-specific. They include generic competencies applied in engineering contexts. For example, under the European-stipulated outcome,

Investigations:

Second Cycle graduates should have:

- the ability to identify, locate and obtain required data;
- the ability to design and conduct analytic, modelling and experimental investigations;
- the ability to critically evaluate data and draw conclusions;
- the ability to investigate the application of new and emerging technologies in their branch of engineering (European Network for Accreditation of Engineering Education 2008, p.6).

Creativity is explicitly noted in the European-stipulated outcomes, but not in those stipulated by Engineers Australia or ABET. Business skills and project management are in the European outcome *Transferable Skills*, and also in the Engineers Australia Stage 1 Competencies, although not in the generic graduate attributes listed by Engineers Australia or the ABET outcomes.

4.2. Results of Studies Identifying Competencies Required by Engineers

Studies to identify important competencies for engineering, or for engineering graduates, have mostly used stakeholder consultation (for example, Spinks *et al.* 2006), occasionally competency modelling (for example, Turley 1992), and even less often, literature reviews and conceptualisation only (for example, Woollacott 2003, Woollacott 2009). Despite the varying methods, consistent themes appear in lists of items. The only exceptions are differing priorities for technical theory, and international differences. Themes and inconsistencies are discussed below.

4.2.1. Frequently Identified Generic Competencies

Communication and teamwork were among the items rated most important in many studies (Connelly and Middleton 1996, Meier *et al.* 2000, Bodmer *et al.* 2002, WCEC 2004, Ferguson 2006a, Reio and Sutton 2006, Male *et al.* 2009a, Nair *et al.* 2009). Integrity and commitment were rated highly important in the studies by Nguyen (1998) and my study (Male *et al.* 2009a). Problem-solving was among items rated highly

important in studies by Ferguson (2006a); (Male *et al.* 2009a); Nguyen; and the WCEC. Ability to learn was a high priority in results of Nguyen's study and that by the WCEC. Management received high ratings in Ferguson's study (2006a), and a customer focus was important in Reio and Sutton's study. Meier *et al.* found all of the above competencies to be important, and additional competencies related to professionalism, for example *appreciating punctuality, timeliness and deadlines; planning work to complete projects on time* (pp. 381-382). The (USA) National Academy of Engineering (2004, pp. 55-57) speculated that engineers will need all of the above, and leadership, business skills and others discussed below. Gathering and analysing information also received high ratings for relevance (WCEC 2004). An interdisciplinary approach was rated as highly important in the survey by the WCEC and in my survey (Male *et al.* 2009a).

In summary, communication and teamwork were among the items rated as most important in many studies. Other generic competencies that feature in the literature are: professionalism and attitudes such as integrity and commitment; ability to learn; management, a customer focus and business skills; leadership; sourcing and analysing information; and an interdisciplinary approach.

4.2.2. Internationality: A Generic Competency with Varied Priority

Patil and Codner (2007) and Galloway (2007) called for "global" competencies. However, the literature reveals variation in this area. It suggests that the observation made by Billing, that a second language is more important in European countries than other western countries, transfers to the engineering context. Swedish participants added the need for a second language to the CDIO syllabus (Crawley 2001), which had initially been developed in the USA (Bankel 2003). A second language, and related items, received relatively low ratings in studies by Ferguson (2006a), and Deans (1999),

and in my study (Male *et al.* 2009a). In the SPINE (Bodmer *et al.* 2002) study, internationality, including having a second language, was more important to engineers in Europe than the USA. However, in the international study by the WCEC (2004), a foreign language was rated higher for relevance to work in China, France and Germany than in the UK, and foreign language was the lowest rated item in the USA, Mexico and Australia. Therefore, the phenomenon could be related to English.

4.2.3. Technical Generic Engineering Competencies

Competence received a high rating in Nguyen's (1998) study. Technical competence was found to be related to workplace adaptation by Reio and Sutton (2006). The (USA) National Academy of Engineering (2004, pp. 55-57) identified a continuing need for *strong analytical skills*, and *practical ingenuity. Analysis and Judgement*, and *Engineering/Technical Knowledge* were core in the study by Brumm and colleagues (Iowa State University 2001, 2006). However, ratings of the importance of technical competencies are inconsistent.

Practical was rated the most important skill in Spinks *et al.*'s (2006) study. However, in the same question of the same study, *Theoretical understanding* was rated to be of relatively low importance among skills or attributes needed by graduates that organizations expected to recruit in ten years' time (2006, pp. 52-53). Similarly, competencies related to technical theory received relatively low importance ratings in my survey (Male *et al.* 2009a).

The low ratings for the importance of technical competencies in some studies raise a quandary, which further questions alignment between engineering education and work:

The two attributes which are rated as more important during education than for employment are *Appreciation of the potential of research* and *Ability to apply knowledge of basic science*. These are, in fact, the traditional priorities of a classical university education. For work, their relevance ranks 21st and 14th respectively (WCEC 2004, p.60).

Despite the low ratings for technical theory in some results, in the question about the profile of the graduate an organization would be most likely to recruit in ten years' time, employers in the study by Spinks *et al.* (2006, p.53) rated *Theoretical understanding* second most important. A quotation from a qualitative part of the study suggested that employers could have been using *Theoretical understanding* as an indicator for competencies such as life-long learning and commitment:

A potential benefit of in-depth knowledge even after the specific domain had become obsolete was that it demonstrated, as one respondent put it, an “ability to master something difficult” (Spinks *et al.* 2006, p.21).

The inconsistency between studies' relative importance ratings for technical theory could also be explained by Elkin's theory of initial and developmental competencies. The studies that asked about competencies for jobs, focused on initial competencies for engineering work for particular stages of engineering. Studies such as the *Engineer of 2020* (National Academy of Engineering 2004), or the part of Spinks *et al.*'s study that asked respondents to select profiles of graduates they would recruit, focused on developmental competencies. Theoretical understanding could be more important as a developmental competency than an initial competency. Employers' ratings in Spinks *et al.*'s study emphasised practical application when asked about importance of skills for graduates and when asked about skill profiles of future graduate recruits, because practical application is both an initial and a developmental competency.

In contrast to technical theory, there is consistent support in the literature for Ferguson's (2006a) conclusion that creativity, innovation and entrepreneurship are required in addition to outcomes expressly stipulated for accreditation in Australia and by ABET, although as noted, these are present in European outcomes. The SPINE study (Bodmer *et al.* 2002) confirmed the importance of these competencies. Problem-solving

features in accreditation outcomes, and was among items highlighted in studies by Derro and Williams (2009), Ferguson (2006a), Nguyen (1998) and the WCEC (2004). My study found that problem-solving and creativity were likely to be important in similar jobs (Male *et al.* under review) (Chapter 7). An interpretation of problem-solving that includes creativity is recommended.

4.2.4. Generic Engineering Competencies Related to the Social and Environmental Context of Engineering

In Ferguson's study (2006a), the attributes, *holistic system engineering approach*, *social and cultural awareness* and *principles of sustainable development*, were rated below significant. This is consistent with relatively low ratings of importance for *systems*, *sustainability* and *social context*, in my study (Male *et al.* 2009a). However, such items are stipulated by accreditation criteria and the National Academy of Engineering (2004) speculated that engineers of 2020 will need *high ethical standards and a strong sense of professionalism... recognizing the broader contexts* (p.56). The difference highlights the significance, raised by the DeSeCo Project (OECD 2002), of the purpose and stakeholders for which competencies are selected.

In summary, the literature that identifies competencies required by engineers consistently includes generic competencies, and these also feature in the literature on competency gaps. Additionally, the literature identifies generic engineering competencies with technical, social and contextual aspects.

5. Difficulty Teaching Generic Competencies in Engineering

Meier (2000) noted that academics face difficulties teaching non-technical competencies in the USA, and Carew *et al.* (2009) found that teaching generic

competencies was usually performed by individual academics without peer support, was rarely evaluated, and rarely included sufficient engineering context.

6. Status of Generic Competencies in Engineering and Engineering Education

Florman (1997) described the low status of non-technical studies in engineering education as a problem that undermined efforts to teach non-technical competencies in engineering. Florman traced the problem to historical features of engineering in the UK and the USA. The literature provides other explanations for a low status of generic competencies, often considered to be non-technical competencies, in engineering education.

6.1. Evolution of Engineering Education

Lloyd (1968, p.43) wrote of Australian academics, “While high academic attainments are a prerequisite to an engineering lectureship, it is rare for a lecturer not to have spent several years in other phases of engineering practice.” This is no longer true.

Prados (1998) and Lang, Cruse, McVey and McMasters (1999) noted shifts in the USA, following World War II, from practical engineering taught by engineers with industry experience to a stronger focus on mathematics and science taught by researchers.

Mills (2002, pp. 25-26) noted similar developments in Australia, and Ferguson (2006a) discussed how, in Australia, creative design was largely replaced with analytical approaches. Together, this literature suggests that an increased emphasis on research rather than practice has narrowed the focus of engineering education towards theory and analysis of abstract problems, and marginalised communication, teamwork, management, definition of problems, practical engineering, and context.

6.2. Gendered Nature of Engineering and Engineering Education

There is extensive literature describing engineering as gendered. Evidence of phenomena suggesting masculine engineering cultures, in which stereotypically feminine traits, such as those related to people and nurture, have low status and abstract science has higher status, have been observed or measured by many researchers (Hacker 1981, Evetts 1998, Fletcher 1999, Faulkner 2006, Bagihole *et al.* 2008, Gill *et al.* 2008, Male *et al.* 2009c). Similar phenomena have been observed in engineering education (Godfrey 2003, Godfroy-Genin and Pinault 2006, Tonso 2007). This gendered culture, described in the literature, is likely to undermine the development of generic competencies in engineering.

7. Conceptual Understanding of Competencies Required by Engineers

7.1. Competencies Required by Engineers Include Knowledge, Skills, Attitudes and Dispositions

Brumm, Hanneman and Mickelson (2006) identified actions that demonstrated competencies. Identified competencies included *Integrity* and *Quality Orientation*, which require personal traits beyond knowledge and skills. The CDIO syllabus includes attitudinal items such as initiative, willingness to take risks, perseverance, flexibility and curiosity (Crawley 2001). Woollacott's (2003) taxonomy includes knowledge, skills and dispositions required for engineering work. Attitudes were rated among the most essential generic skills and attributes in Nguyen's (1998) study. Therefore, an understanding of competencies including knowledge, skills, attitudes and dispositions is evident in engineering literature.

7.2. Competencies Required by Engineers Exist in Constellations with Varying Profiles of Importance

A project commissioned by the OECD (2002, pp. 14-16) provided a conceptual understanding of competencies as existing in “constellations” with varying profiles of importance for differing contexts. The following literature supports this understanding among generic engineering competencies.

The 1990s (Johnson 1996b) review in Australia found that engineers with various competency profiles are required. This is partly why the generic graduate attributes are broad rather than specific. The most recent Australian review of engineering education identified two types of engineers requiring different competency profiles:

Future education programs for professional engineers may need to be designed more clearly and purposefully for practice in advanced engineering science and technology on one hand, or in systems integration and project management on the other.

(Johnston *et al.* 2008, p.69)

Spinks *et al.* (2006) concluded that three types of engineer each require a different profile of skills. Ferguson found that graduate attributes had varying importance in different industries (Ferguson 2006a). Barley (2005) emphasised that the understanding that engineers perform different work in different roles, even more so than in different industries, is important for researchers of engineering practice.

Capabilities identified as important in Scott and Yates’ (2002) study differed from those listed in other studies due to the graduate-level perspective. Deans (1999) found that the rated importance, to an engineer’s job, of professionally-oriented subjects such as *engineering economics* and *marketing*, increased with experience, and the importance of the design process decreased. Trevelyan and Tilli (2007) state that management is embedded in all engineering jobs. In an industry competency model for managers in the

construction industry in the UK, required levels of technical competence decrease as required managerial competence increases (Maxwell-Hart and Marsh 2001).

Therefore, literature has identified competencies that are important across all engineering jobs, yet have relative importance which varies across jobs, particularly with career progression.

7.3. It is more helpful to Focus on Competencies Required by Engineers as Integrated, Rather than Existing in Two Distinct Groups

Faulkner found that the tendency for engineers to classify the work of engineers into technical work, which is seen as the real engineering work, and non-technical work, which is not seen as engineering, is both flawed and harmful to the profession (Faulkner 2007).

Markes (2006) reviewed UK literature on generic competencies in engineering. She concluded that several changes were needed for successful skills development:

Enhancing employability requires a holistic approach integrating knowledge, work experience and technical and interactive skills development... Efforts to increase employability need to be holistic... The holistic approach is also likely to change the mindset/attitude and win the support of the academic and business world and decrease the perceived antipathy towards skills development in general (Markes 2006, p.648).

The most recent review of engineering education in Australia suggested that the expression of stand-alone generic graduate attributes might have contributed to industry members' perceptions of graduates having low technical theoretical and practical skills (Johnston *et al.* 2008).

Jelsma and Woudstra (1997) reported that although it is easiest for academic staff to teach disciplines separately, such as engineering science, management and philosophy,

the disciplines remained separate in the practice of graduates, and disciplines such as philosophy were seen as easy options by students. They found that it was necessary to teach using examples in engineering practice. Similarly, ethics has been embedded within engineering contexts (for example, Johnston *et al.* 2000)

Meier *et al.* (2000) recommended integration of concepts within existing modules, and use of practical activities. In recent decades, problem-based and project-based learning have experienced growing popularity. CDIO (CDIO) and Engineers Without Borders (Dowling *et al.* 2010) are examples of initiatives supporting these. Such initiatives develop generic and engineering-specific competencies together.

8. Recommendation and Conclusion Based on the Literature

The above literature review revealed the following. The literature identifies gaps between competencies developed in engineering education and required for engineering work. Generic competencies feature in identified gaps and feature as important in stipulated education outcomes and studies identifying competencies required by engineers. Literature claims that academics have difficulty teaching generic competencies. The literature suggests that the low status of generic competencies compared with technical competencies is part of the problem.

Based on these points from the literature, I propose that a tactful approach to improve development of generic competencies in engineering education will be to focus on developing “generic engineering competencies”.

Focusing on “generic engineering competencies”, should help develop generic competencies within engineering cultures and university cultures that under-value generic competencies. Students learn the culture nurtured by the faculty (Ihsen 2005). Academics’ use of the term “generic engineering competencies” will model respect for

both aspects of engineering competencies: generic competencies and engineering-specific competencies, overcoming the relatively low status of generic competencies in engineering and engineering education cultures. The term implies integration of generic and generic engineering competencies, as is recommended by literature in the final section of the review above.

The literature supports a conceptual understanding of “generic engineering competencies” as integrating generic and engineering-specific aspects and technical and non-technical aspects, being important across all engineering jobs but with varying relative importance across jobs, and including initial and developmental aspects, and encompassing knowledge, skills, attitudes and dispositions.

Adapting a definition for key competencies from the DeSeCo Project (OECD 2002), I suggest the following definition:

“Generic engineering competencies” are knowledge, skills, attitudes and dispositions that are important across all areas of engineering, and facilitate the success of engineers as individuals and their contributions as engineers to a well-functioning society.

Engineering educators should focus on developing “generic engineering competencies” in their students.

References

References are included in the references for the main thesis.