Education Research and Perspectives, Vol.37, No.1

Generic Engineering Competencies: A Review and Modelling Approach

Sally A. Male†

The University of Western Australia

This paper puts forward the view that engineering educators have a responsibility to prepare graduates for engineering work and careers. The current literature reveals gaps between the competencies required for engineering work and those developed in engineering education. Generic competencies feature in these competency gaps. Literature suggests that improving the development of generic competencies in engineering graduates has met with barriers. One identified problem is that a relatively low status is assigned to generic competencies in engineering education. This review focuses on competencies that are required by professional engineers across all engineering disciplines, in Australia, Europe, New Zealand, and the USA. The literature suggests that engineering educators should focus on developing "generic engineering competencies" rather than separate generic competencies and engineering competencies. A method, developed at the University of Western Australia for identifying the generic engineering competencies required by engineers graduating in Australia, is outlined.

Introduction

Multiple studies have identified generic competencies among the gaps between the competencies developed during engineering education and those required for engineering work. This paper reviews related literature to clarify the problem and identify ways in which it can be addressed. The motivation for this work came from a project initiated by the engineering Industry Advisory Board of the University of Western Australia. The goal of the latter project was to "close the loop" in the continuous improvement of engineering education by profiling graduate competencies (Male & Chapman, 2005).

---

† Address for correspondence: Dr. Sally Male, Faculty of Engineering, The University of Western Australia, 35 Stirling Highway, Crawley, Western Australia, 6009. Email: sally.male@uwa.edu.au.

This paper puts forward 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.

In any discussion of generic competencies, it is necessary first to clarify terms. Confusion arises with the use of terms such as "competencies", "generic competencies", and related terms such as "generic attributes", "generic skills" and "employment skills". Lists, studies, and applications are often based on similar yet varied constructs (Billing, 2003). The scope of this review is not restricted to any one conceptual understanding.

In this paper, the term "generic" is used to refer to attributes, competencies, or skills that are important to graduates across all disciplines *including* engineering, while the term "generic engineering" is used to refer to those that are important to graduates across all engineering disciplines.

The remainder of the paper focuses on reviewing the literature related to generic competencies in engineering education. Recommendations based on this literature are then made, followed by an outline of the method developed at the University of Western Australia to identify the competencies required of Australian graduate engineers.

Competency Gaps in Engineering Graduates

Many authors have discussed how changes in the professional context of engineering have influenced demands of engineers and engineering education. These 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 (Becker, 2006; Beder, 1998; Ferguson, 2006b; Galloway, 2007; Green, 2001; Mills, 2002;

National Academy of Engineering, 2004; Ravesteijn, Graaff, & Kroesen, 2006). 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 identified 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. For example, Grinter (1955) highlighted a need for development of better communication skills in engineering graduates.

More recently, gaps in communication, leadership, and social skills were highlighted in the SPINE study (Bodmer, Leu, Mira, & Rutter, 2002), and many surveys and reviews of engineering education have found the largest competency gaps in similar areas (Ashman, Scrutton, Stringer, Mullinger, & Willison, 2008; Bons & McLay, 2003; Connelly & Middleton, 1996; Johnson, 1996a; Nair, Patil, & Mertova, 2009; WCEC, 2004; Williams, 1988). The largest competency gap identified by Scott and Yates (2002) was emotional intelligence.

Promisingly, the most recent Australian review of engineering education noted improved oral communication and teamwork in engineering programs, although gaps in written communication remained (A. Johnston, King, Bradley, & O'Kane, 2008). Similarly, employers’ ratings indicated relative satisfaction with the 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 (Beder, 1998; Holt & Solomon, 1996; A. Lee & Taylor, 1996a, 1996b). Schön’s study of engineering design from a philosopher's perspective raised similar issues (Schon, 1983; Waks, 2001). Comments received in the recent review of engineering education in Australia also support this concern (A. 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 (Spinks et al., 2006; WCEC, 2004). These were highlighted as gaps by graduates in a survey based at the University of Western Australia (Male, Bush, & Chapman, 2010) and employers in a recent Australian review (A. Johnston et al., 2008). Management and business items were found to be among the competencies with the largest 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*. In our own research in Western Australia, however, Bush, Chapman, and I found indicators of improvement in the engineering business skills of graduates over recent decades (Male et al., 2010).

The most recent review in Australia (A. 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 raised in the engineering education literature feature generic competencies.

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 that students and societies place in them to do this, as is recognised by program accreditation. However, the alignment between engineering education and work has been questioned in several studies, as outlined below.

Previous studies on graduates have indicated no significant relationship between academic grades and job performance. The latter result has been obtained in studies both in the UK (Briggs, 1985; Harvey & Lemon, 1994) and in the USA (Lee, 1986). Conversely, Newport and Elms (1997) in New Zealand, found that *mental agility*, *enterprise* and *interpersonal capabilities* did correlate with job effectiveness. In their conclusions (p. 330), the latter authors stated that "Significantly, academic achievement showed virtually no correlation with engineering effectiveness."

Relatively recent qualitative research in Sweden investigated the transition from study to work (Dahlgren, Hult, Dahlgren, Hard, & Johansson, 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.

Competencies Required by Engineers

Taking the view that engineering education should be aligned with engineering work, I now consider conclusions from 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" as those required to develop within a job, and perhaps into a higher level job. Anderson (J.L. Anderson in Bodmer et al., 2002, p.11) stated that "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.

Stipulated Outcomes in Accreditation Criteria for Engineering Education Programs

Items with both generic and generic engineering aspects are included among the engineering education outcomes stipulated in Australia, Europe, New Zealand, the USA, and internationally (Accreditation Board for Engineering and Technology, 2008, p.2; Engineering Council, 2009; Engineers Australia, 2005; European Network for Accreditation of Engineering Education, 2008; Institution of Professional Engineers New Zealand, 2009; International Engineering Alliance, 2009; Maillardet, 2004; Quality Assurance Agency for Higher Education, 2006).

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 (Accreditation Board for Engineering and Technology, 2008, p.2):

> (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; and
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

An alternative structure, which partly separates generic items from generic engineering items, appears in the European-stipulated outcomes (European Network for Accreditation of Engineering Education, 2008, p.4). These are:

- Knowledge and Understanding;
- Engineering Analysis;
- Engineering Design;
- Investigations;
- Engineering Practice; and
- Transferable Skills.

Of these, only *Transferable Skills* is generic. *Transferable Skills* encompasses the non-technical ABET outcomes. Despite this, the other European outcomes are not purely engineering-specific. They include generic competencies applied in engineering contexts. For example, under the European-stipulated outcome, *Investigations* (European Network for Accreditation of Engineering Education, 2008, p.6), it indicates that 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; and
- the ability to investigate the application of new and emerging technologies in their branch of engineering.

Creativity is noted explicitly 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.

Studies on Identifying Competencies Required by Engineers

Studies conducted 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, 2009). Despite the varying methods, consistent themes appear in the item lists. The only exceptions are differing priorities for technical theory, and international differences. Themes and inconsistencies are discussed below.

Frequently Identified Generic Competencies. Communication and teamwork are frequently among the items rated most important amongst the generic competencies in many studies (Bodmer et al., 2002; Connelly & Middleton, 1996; Ferguson, 2006a; Male, Bush, & Chapman, 2009; Meier et al., 2000; Nair et al., 2009; Reio & Sutton, 2006; WCEC, 2004). Integrity and commitment were also rated highly important in the studies by Nguyen (1998) and in our own study at the University of Western Australia (Male et al., 2009). Problem solving was among items rated highly important in studies by Ferguson (2006a), Male et al. (2009), Nguyen (1998), and the WCEC. Ability to learn was a high priority in results of Nguyen's study and the WCEC. Management received high ratings in Ferguson's study (2006a) and customer focus was important in Reio and Sutton's study.

Meier et al. found all of the above competencies to be important, as well as 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 speculated that engineers will need all of the above, and leadership, business skills and others that are discussed below (2004, pp.55-57). 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 our own Western Australian survey (Male et al., 2009).

In summary, communication and teamwork are among the items rated as most important for engineering, or for engineering graduates, 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.

Internationality: A Generic Competency with Varied Priority. In addition to the above, some researchers such as Patil and Codner (2007) and Galloway (2007) have called for the development of "global" competencies in engineering students. 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), Deans (1999), and in our own previous study (Male et al., 2009). 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 skills was the lowest rated item in the USA, Mexico and Australia. Therefore, the phenomenon could be related to English.

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 identified a continuing need for *strong analytical skills*, and *practical ingenuity* (National Academy of Engineering, 2004, pp. 55-57). *Analysis and Judgement*, and *Engineering/Technical Knowledge* were core in the study by Brumm et al. (2006; Iowa State University, 2001). However, ratings of the importance of technical competencies were inconsistent.

Practical was rated the most important skill in Spinks et al.'s (2006) study. However, in the same question drawn from the same study, *Theoretical understanding* was rated to be of relatively low importance among skills or attributes needed by graduates that organisations expected to recruit in ten years' time (2006, pp.52-53). Similarly, competencies related to technical theory received relatively low importance ratings in our survey (Male et al., 2009).

The low ratings for the importance of technical competencies in some studies raise a quandary, which further questions alignment between engineering education and work (WCEC, 2004, p.60):

> 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…

Despite the low ratings for technical theory in some results, in the question about the profile of the graduate an organisation would be most likely to recruit in ten years' time, employers in the study by Spinks et al. rated *Theoretical understanding* second most important (2006, p. 53). 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 (Spinks et al., 2006, p.21):

> 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'.

The inconsistency between the relative importance ratings across studies for technical theory could also be explained by Elkin's theory of initial and developmental competencies. The studies that asked about competencies for jobs, focussed 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, focussed 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. As noted, however, 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 the items highlighted in studies by Derro and Williams (2009), Ferguson (2006a), Nguyen (1998), and the WCEC (2004). Our study found that problem solving and creativity were likely to be important in similar jobs (Male, Bush, & Chapman, under review). An interpretation of problem solving that includes creativity is recommended.

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 as below significant. This is consistent with the relatively low importance ratings for *systems*, *sustainability*, and *social context*, in our study (Male et al., 2009).

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* (pp. 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.

Difficulties Associated with 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.

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 the low status of generic competencies, often considered to be non-technical competencies, in engineering education.

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.

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 (Bagihole, Powell, Barnard, & Dainty, 2008; Evetts, 1998; Faulkner, 2006; Fletcher, 1999; Gill, Sharp, Mills, & Franzway, 2008; Hacker, 1981; Male, Bush, & Murray, 2009). Similar phenomena have been observed in engineering education (Godfrey, 2003; Godfroy-Genin & Pinault, 2006; Tonso, 2007). This gendered culture, described in the literature, is likely to undermine the development of generic competencies in engineering.

A Conceptual Clarification of the Competencies Required by Engineers

Competencies Required by Engineers Include Knowledge, Skills, Attitudes, and Dispositions

Brumm, Hanneman and Mickelson (2006) identified various 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.

Competencies Required by Engineers Exist in Constellations with Varying Profiles of Importance

The DeSeCo Project commissioned by the OECD provided a conceptual understanding of competencies as existing in “constellations” with varying profiles of importance for differing contexts (OECD, 2002, pp. 14-16). The following literature supports this understanding among generic engineering competencies. A 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 identified two types of engineers requiring different competency profiles (A. Johnston et al., 2008, p. 69):

> 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.

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 & Marsh, 2001).

Therefore literature has identified competencies that are important across all engineering jobs, yet have relative importance which varies across jobs, particularly with respect to career progression.

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 (p.648):

> 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.

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 (A. 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, S. Johnston, McGregor, & Taylor, 2000).

Meier et al. (2000) recommended integration of concepts within existing modules, and use of practical experiential activities. In recent decades problem-based and project-based learning have experienced growing popularity. CDIO (CDIO) and Engineers Without Borders (Dowling, Carew, & Hadgraft, 2010) are examples of initiatives supporting these. Such initiatives develop generic and engineering-specific competencies together.

Recommendations Based on the Literature

The above literature review identified gaps between the competencies developed in engineering education and those required for engineering work. Generic competencies feature in these identified gaps, and are deemed to be important in stipulated education outcomes and studies identifying the competencies required by engineers. The literature suggests, however, that academics have difficulties in teaching generic competencies, partly because of the low status assigned to generic competencies in comparison to technical competencies in engineering.

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".

Focussing on "generic engineering competencies", should help develop generic competencies within engineering 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 an integration of generic and generic engineering competencies, as is recommended by the literature reviewed in this paper.

The literature supports a conceptual understanding of "generic engineering competencies" that: integrates generic and engineering-specific aspects and technical and non-technical aspects; are important across all engineering jobs but with varying relative importance across jobs; include initial and developmental aspects; and encompass knowledge, skills, attitudes and dispositions.

Adapting a definition for key competencies from the Definition and Selection of Competencies (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.

Method Developed at the University of Western Australia to Identify Generic Competencies

At the University of Western Australia, in the Competencies of Engineering Graduates (CEG) Project, in collaboration with Mark Bush and Elaine Chapman, I developed a method to identify the generic engineering competencies required by engineers graduating in Australia. The method has since been adapted from engineering to other professions such as Business and Medicine (e.g., Jackson, 2009, and in this issue). The method was based on a conceptual framework for understanding competencies, developed by the DeSeCo Project (OECD, 2002). Key features of the framework are that competencies: include knowledge, skills, attitudes, and dispositions; are manifested in responses to demands; are inter-related; and exist in constellations with varying importance in various contexts. Selection of competencies depends on the stakeholders and the purpose for which they are selected. In the CEG Project, the framework was adapted such that engineering jobs determined demands and contexts.

A CEG Project Industry Advisory Committee was formed from within the Industry Advisory Board which initiated the CEG Project. Members advised that, rather than seeking engineering graduates who will be useful immediately, engineering employers seek to recruit graduates who will value add once they become “established engineers”. Therefore, the Project focused on competencies required by established engineers, that is, with five to twenty years of experience.

Competencies were identified from a broad range of literature and reduced to a list of 64 competencies that, based on the literature, could be expected to be required by engineers. In a survey, 300 established engineers rated the importance of each competency for performing their jobs well. This confirmed the importance of all sixty four competencies. Factor analysis of the ratings revealed factors of competencies with correlated ratings. These factors were conceptually reasonable.

Job incumbents know their jobs better than anyone else, but responses about their own jobs can sometimes be influenced by factors such as self-image and lack of a broader perspective (Morgeson, Delaney-Klinger, Mayfield, Ferrara, & Campion, 2004). Therefore, in a second survey, 250 senior engineers who had managed or supervised established engineers also rated the competencies and thereby confirmed the results of the first survey.

In addition to competency ratings, participants in the first survey provided data about their jobs, for example, key responsibilities, size of organization and engineering discipline. Multivariate analysis of variance of the factor scores across job characteristics revealed that, as expected based on the DeSeCo framework, the relative importance of the competency factors varied across engineering jobs. A focus group session, with participants from diverse roles in engineering, was used to validate and refine the competency model.

The resulting competency model could be used directly to help improve engineering education, and also to close the loop in improving of engineering education by collecting workplace supervisors' ratings of the competencies of graduates.

Conclusions

Based on a literature review, this paper recommends that engineering educators should help their students to develop competencies that are often called "generic competencies", by focussing on "generic engineering competencies" which encompass technical and non-technical competencies required across all disciplines of engineering.

The paper outlined the method developed at UWA to identify the generic engineering competencies required by engineers graduating in Australia, in order to help profile the competencies of graduates and consequently improve engineering education. Communication, teamwork, professional attitudes, engineering business skills, problem solving, critical thinking, creativity, and practical engineering skills were perceived as highly important to the work of established engineers (Male et al., 2009). In an eleven-factor competency model developed from the importance ratings for competencies, the competency factors with the highest factor scores were Communication, Teamwork, Self-Management, Professionalism and Ingenuity (Male et al., under review). The method has been adopted within other professions to date.

Acknowledgments

I am grateful to Caroline Baillie, Mark Bush, Elaine Chapman and James Trevelyan for their support.

References

Accreditation Board for Engineering and Technology. (2008). *Criteria for Accrediting Engineering Programs, Effective for Evaluations During the 2009-1010 Accreditation Cycle*. Baltimore MD: Accreditation Board for Engineering and Technology.

Ashman, P. J., Scrutton, S., Stringer, D., Mullinger, P. J., & Willison, J. (2008). Stakeholder Perceptions of Chemical Engineering Graduate Attributes at the University of Adelaide, *CHEMECA*. Newcastle City Hall, New South Wales, Australia.

Bagihole, B., Powell, A., Barnard, S., & Dainty, A. (2008). *Researching Cultures in Science, Engineering & Technology: An analysis of current and past literature*. Bradford: Loughborough University.

Bankel, J., Berggren, K.-F., Blom, K., Crawley, E. F., Wiklund, I., & Östlund, S. (2003). The CDIO syllabus: a comparative study of expected student proficiency. *European Journal of Engineering Education, 28*(3), 297-315.

Barley, S. R. (2005). What we know (and mostly don't know) about technical work. In S. Ackroyd, R. Batt, P. Thompson & P. S. Tolbert (Eds.), *The Oxford Handbook of Work and Organization* (pp. 376-403): Oxford University Press.

Becker, F. S. (2006). Globalization, curricula reform and the consequences for engineers working in an international company. *European Journal of Engineering Education, 31*(3), 261-272.

Beder, S. (1998). *The New Engineer, Management and Professional Responsibility in a Changing World*. Melbourne: Macmillan Education Australia.

Billing, D. (2003). Generic Cognitive Abilities in Higher Education: An International Analysis of Skills Sought by Stakeholders. *Compare, 33*(3), 335-350.

Bodmer, C., Leu, A., Mira, L., & Rutter, H. (2002). *SPINE: Successful Practices in International Engineering Education*: Engineers Shape our Future IngCH.

Bons, W., & McLay, A. (2003, 29 Sept - 1 Oct). *Re-engineering Engineering Curricula for Tomorrow's Engineers.* Paper presented at the 14th Annual Australian Association for Engineering Education Conference, Melbourne.

Briggs, B. F. N. (1985). Analysis of the entrance qualifications to a CNAA honours degree course, final results and subsequent career achievement. *International Journal of Electrical Engineering Education, 22*(3), 265-279.

Brumm, T. J., Hanneman, L. F., & Mickelson, S. K. (2006). Assessing and developing program outcomes through workplace competencies. *International Journal of Engineering Education, 22*(1), 123-129.

Carew, A. L., Therese, S., Barrie, S., Bradley, A., Cooper, P., Currie, J., et al. (2009). *Engineer Meta-Attributes Project EMAP: Systems Thinking and Reflective Practice in Engineering Education: Final Report CG623 Teaching & assessment of meta-attributes in Engineering: identifying, developing and disseminating good practice (EMAP).* Strawberry Hills NSW: Australian Teaching and Learning Council.

CDIO. *CDIO*. Retrieved January 9, 2010, from http://www.cdio.org/

Connelly, J. D., & Middleton, J. C. R. (1996). Personal and Professional Skills for Engineers: One Industry's Perspective. *Engineering Science and Education Journal, 5*(3), 139-144.

Crawley, E. F. (2001). *The CDIO Syllabus: A Statement of Goals for Undergraduate Engineering Education*: Massachusetts Institute of Technology.

Dahlgren, M. A., Hult, H., Dahlgren, L. O., Hard, H., & Johansson, K. (2006). From senior student to novice worker: learning trajectories in political science, psychology and mechanical engineering. *Studies in Higher Education, 31*(5), 569 - 586.

Deans, J. (1999). The educational needs of graduate mechanical engineers in New Zealand. *European Journal for Engineering Education, 24*(2), 151-162.

Derro, M. E., & Williams, C. R. (2009). Behavioural Competencies of Highly Regarded Sustems Engineers at NASA, *Aerospace Conference* (pp. 1-17). Big Sky MT: IEEE.

Dowling, D., Carew, A. L., & Hadgraft, R. (2010). *Engineering Your Future*. Milton, Queensland: Wiley.

Elkin, G. (1990). Competency-based human resource development. *Industrial & Commercial Training, 22*(4), 20-25.

Engineering Council. (2009). *Regulations for Registration*. London: Engineering Council.

Engineers Australia. (2005). *Engineers Australia Policy on Accreditation of Professional Engineering Programs* (No. P02). Barton, ACT: Engineers Australia Accreditation Board.

European Network for Accreditation of Engineering Education. (2008). *EUR-ACE Framework Standards for the Accreditation of Engineering Programmes*. Brussels.

Evetts, J. (1998). Managing the technology but not the organisation: women and career in engineering. *Women in Management Review, 13*(8), 283-290.

Faulkner, W. (2006). Genders in/of Engineering: The University of Edinburgh. Retrieved March 18, 2009 from www.issti.ed.ac.uk/documents.php?item=25

Faulkner, W. (2007). "Nuts and Bolts and People": gender-troubled engineering identities. *Social Studies of Science, 37*(3), 331-356.

Ferguson, C. (2006a). *Attributes for Australian Mechanical Engineers through Proximal and Distance Education.* Doctor of Technology, Deakin University.

Ferguson, C. (2006b). Defining the Australian Mechanical Engineer. *European Journal of Engineering Education, 31*(4), 471-485.

Fletcher, J., K. (1999). *Disappearing acts: gender, power and relational practice at work*. Cambridge, MA: MIT Press.

Florman, S. (1997). Non-technical studies for engineers: The challenge of relevance. *European Journal of Engineering Education, 22*(3), 249-258.

Galloway, P. D. (2007). *The 21st-Century Engineer: A Proposal for Engineering Education Reform*. Reston, Virginia: ASCE Press.

Gill, J., Sharp, R., Mills, J., & Franzway, S. (2008). I still wanna be an engineer! Women, education and the engineering profession *European Journal of Engineering Education, 33*(4), 391-402.

Godfrey, J. E. (2003). *The Culture of Engineering Education and its Interaction with Gender: A Case Study of a New Zealand University*. PhD, Curtin University of Technology, Perth.

Godfroy-Genin, A.-S., & Pinault, C. (2006). The benefits of comparing grapefruits and tangerines: a toolbox for European cross-cultural comparisons in engineering education using this toolbox to study gendered images of engineering among students. *European Journal of Engineering Education, 31*(1), 23-33.

Green, M. (2001). Educating the new engineer. *Transactions of Multi-Disciplinary Engineering, GE25*, 39-50.

Grinter, L. E. (1955). Report of the committee on the evaluation of engineering education. *Journal of Engineering Education, 46,* 25-60.

Hacker, S. (1981). The culture of engineering: Woman, workplace and machine. *Women, Technology and Innovation, 4*(3), 341-353.

Harvey, R., & Lemon, N. (1994). Personal factors, education and the effectiveness of professional engineers. *European Journal of Engineering Education, 19*(3), 351.

Holt, J. E., & Solomon, F. L. (1996). Engineering education - the way ahead. *Australasian Journal of Engineering Education, 7*(1).

Ihsen, S. (2005). Special gender studies for engineering? *European Journal of Engineering Education, 30*(4), 487-494.

Institution of Professional Engineers New Zealand. (2009). *Graduate Competency Profiles*. Wellington: Institution of Professional Engineers New Zealand.

International Engineering Alliance. (2009). *Graduate Attributes and Professional Competencies Version 2*.

Iowa State University. (2001). *Iowa State University Engineering & Technology Workplace Competencies*. Retrieved September 13, 2007, from http://learn.ae.iastate.edu/competencydefinitions.pdf

Jackson, D. (2009) Profiling industry relevant management graduate competencies: the need for a fresh approach. *International Journal of Management Education, 8*(1), 85-98.

Jelsma, J., & Woudstra, E. (1997). Integrated training of engineers for a changing society. *European Journal for Engineering Education, 22*(3), 277-293.

Johnson, P. (1996a). *Changing the Culture: Engineering Education into the Future Review Report*. Canberra: The Institution of Engineers Australia.

Johnson, P. (1996b). *Changing the Culture: Engineering Education into the Future: Task Force Reports*. Canberra: The Institution of Engineers Australia,.

Johnston, A., King, R., Bradley, A., & O'Kane, M. (2008). *Addressing the Supply and Quality of Engineering Graduates for the New Century*. Sydney: The Carrick Institute for Learning and Teaching in Higher Education.

Johnston, S., McGregor, H., & Taylor, E. (2000). Practice-focused ethics in Australian engineering education. *European Journal for Engineering Education, 25*(4), 315-324.

Lang, J. D., Cruse, S., McVey, F. D., & McMasters, J. (1999). Industry expectations of new engineers: A survey to assist curriculum designers. *Journal of Engineering Education, 88*(1), 43-51.

Lee, A., & Taylor, E. (1996a). The dilemma of obedience: A feminist perspective on the making of engineers. *Educational Philosophy and Theory, 28*(1), 57-75.

Lee, A., & Taylor, E. (1996b). *'Priets of the new epoch'? engineering, critique and the role of the university*. Paper presented at the Knowledge and Discourse: An International Multi-Disciplinary Conference, University of Hong Kong.

Lee, D. M. S. (1986). Academic achievement, task characteristics, and first job performance of young engineers. *IEEE Transactions on Engineering Management, EM33*(3), 127-133.

Lloyd, B. E. (1968). *The Education of Professional Engineers in Australia*. Melbourne: The Association of Professional Engineers, Australia.

Maillardet, F. (2004). What outcome is engineering education trying to achieve? In C. Baillie & I. Moore (Eds.), *Effective Learning and Teaching in Engineering* (pp. 27-35). London: RoutledgeFalmer.

Male, S. A., Bush, M. B., & Chapman, E. S. (2009). Identification of competencies required by engineers graduating in Australia. In C. Kestell, S. Grainger & J. Cheung (Eds.), *20th Conference*

of the Australasian Association for Engineering Education: Engineering the Curriculum (pp. 882-887). The University of Adelaide: School of Mechanical Engineering, The University of Adelaide.
Male, S. A., Bush, M. B., & Chapman, E. S. (in press). Perceptions of competency deficiencies in engineering graduates. *Australasian Journal of Engineering Education*.
Male, S. A., Bush, M. B., & Chapman, E. S. (under review). Generic competencies required by engineers graduating in Australia.
Male, S. A., Bush, M. B., & Murray, K. (2009). Think engineer, think male? *European Journal of Engineering Education, 34*(5), 455-464.
Male, S. A., & Chapman, E. S. (2005, 26-29 September, 2005). *Assessing the generic competencies of engineering graduates*. Paper presented at the 4th ASEE / AaeE Global Colloquium on Engineering Education, Sydney.
Markes, I. (2006). A review of literature on employability skill needs in engineering. *European Journal for Engineering Education, 31*(6), 637-650.
Maxwell-Hart, G., & Marsh, G. (2001). *Management development in the construction industry: guidelines for the construction professional* (2nd ed.). London: Thomas Telford Publishing for the Institution of Civil Engineers.
Meier, R. L., Williams, M. R., & Humphreys, M. A. (2000). Refocusing our efforts: assessing non-technical competency gaps. *Journal of Engineering Education, 89*(3), 377-385.
Mills, J. E. (2002). *The effectiveness of project-based learning in structural engineering.* PhD, Curtin University of Technology, Perth.
Morgeson, F. P., Delaney-Klinger, K., Mayfield, M. S., Ferrara, P., & Campion, M. A. (2004). Self-presentation processes in job analysis: a field experiment investigating inflation in abilities, tasks, and competencies. *Journal of Applied Psychology, 89*(4), 674-686.
Nair, C. S., Patil, A., & Mertova, P. (2009). Re-engineering graduate skills - a case study. *European Journal of Engineering Education, 34*(2), 131 - 139.

National Academy of Engineering. (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: National Academies Press.
Newport, C. L., & Elms, D. G. (1997). Effective engineers. *International Journal of Engineering Education, 13*(5), 325-332.
Nguyen, D. (1998). The essential skills and attributes of an engineer: a comparative study of academics, industry personnel and engineering students. *Global Journal of Engineering Education, 2*(1), 65-76.
OECD. (2002). *Definition and Selection of Competencies (DeSeCo) Theoretical and Conceptual Foundations: Strategy Paper*: Organisation for Economic Co-operation and Development.
Patil, A., & Codner, G. (2007). Accreditation of engineering education: review, observations and proposal for global accreditation. *European Journal of Engineering Education, 32*(6), 639 - 651.
Prados, J. W. (1998). Engineering education in the united states: past, present and future, *International Conference on Engineering Education* (pp. Paper 255). Rio de Janeiro.
Quality Assurance Agency for Higher Education. (2006). *Subject Benchmark Statement Engineering*. Retrieved August 29, 2007, from www.qaa.ac.uk/academicinfrastructure/benchmark/statements/Engineering06.pdf
Ravesteijn, W., Graaff, E. D., & Kroesen, O. (2006). Engineering the future: the social necessity of communicative engineers. *European Journal of Engineering Education, 31*(1), 63-71.
Reio, T. G., & Sutton, F. C. (2006). Employer assessment of work-related competencies and workplace adaptation. *Human Resource Development Quarterly, 17*(3), 305-324.
Schon. (1983). *The Reflective Practitioner*: Harper Collins.
Scott, G., & Yates, K. W. (2002). Using successful graduates to improve the quality of undergraduate engineering programmes. *European Journal of Engineering Education, 27*(4), 363-378.
Shuman, L. J., Besterfield-Sacre, M., & McGourty, J. (2005). The ABET "Professional Skills" - Can they be taught? Can they be assessed? *Journal of Engineering Education, 94*(1), 41-55.

Spinks, N., Silburn, N., & Birchall, D. (2006). *Educating Engineers for the 21st Century: The Industry View*. London: The Royal Academy of Engineering.

Tonso, K. L. (2007). *On the Outskirts of Engineering*. Rotterdam: Sense Publishers.

Trevelyan, J. P., & Tilli, S. (2007). Published research on engineering work. *Journal of Professional Issues in Engineering Education and Practice 133*(4), 300-307.

Turley, R. T. (1992). Essential Competencies of Exceptional Professional Software Engineers. *Dissertation Abstracts International, 53*(1-B), 400.

Waks, L. J. (2001). Donald Schon's philosophy of design and design education. *International Journal of Technology and Design Education, 11*, 37-51.

WCEC. (2004). *How Does Chemical Engineering Education Meet the Requirements of Employment?* Frankfurt: World Chemical Engineering Council.

Williams, B. S. (1988). *Review of the Discipline of Engineering*. Canberra: Commonwealth of Australia.

Woollacott, L. C. (2003). Dealing with under-representation in engineering education Part 1: Defining the Goal: A Taxonomy of Engineering Competency, *WFEO/ASEE e-Conference*: University of Witwatersrand.

Woollacott, L. C. (2009). Validating the CDIO syllabus for engineering education using the taxonomy of engineering competencies. *European Journal of Engineering Education, online first*, 1-15.