Understanding generic engineering competencies

Sally A Male
The University of Western Australia, Perth, Australia
sally.male@uwa.edu.au

Mark B Bush
The University of Western Australia, Perth, Australia
mark.bush@uwa.edu.au

Elaine S Chapman
The University of Western Australia, Perth, Australia
elaine.chapman@uwa.edu.au

***Abstract**: This paper contributes to understanding of the generic engineering competencies required by engineers graduating in Australia, and to competency theory. A large project was conducted to identify the generic engineering competencies required by engineers graduating in Australia. The methodology adapted a theoretical framework for understanding key competencies developed by the Definition and Selection of Competencies Project commissioned by the Organisation for Economic Cooperation and Development. The phases of the project included a literature review, a panel session, two large scale surveys and a focus group. By reflecting on the whole research project, this paper provides insight into the nature of competencies required by engineers in Australia. Implications for engineering educators are described.*

Introduction

In Australia engineering education programs are accredited by Engineers Australia (EA). The accreditation criteria stipulate that engineering students of accredited programs must develop the stipulated ten generic graduate attributes and the more detailed Stage 1 Competency Standards (EA, 2005, 2008). The accreditation criteria drive change in engineering education programs, evaluation methods, and even the foci of benchmarking exercises. Therefore it is critical that the nature of generic engineering competencies required by engineers graduating in Australia is understood well by accreditation developers, accreditation panels and engineering educators.

However, generic competency theory has suffered from a multitude of related terms such as generic attributes, employability skills, and key competencies (Billing, 2003), and multiple conceptual understandings (Barrie, 2006). This has confused the use of competencies and added to the need for clarity.

The international multi-disciplinary Definition and Selection of Competencies (DeSeCo) Project developed a conceptual framework for competencies (OECD, 2002). The Project focused on key competencies for a successful life and contribution to a well-functioning society. This paper reports conclusions about the nature of generic engineering competencies, made from a project that adapted the DeSeCo theoretical framework for understanding competencies, to generic engineering competencies.

Methodology

The DeSeCo framework describes competencies as encompassing knowledge, skills, attitudes and dispositions and manifesting in responses to demands within contexts. The framework describes competencies as inter-related and existing in "constellations" of competencies with weights that vary across contexts (OECD, 2002, p.14).

Components of the framework were adopted directly in this study. Competencies identified in this study were assumed to encompass knowledge, skills, attitudes and dispositions. Competencies encompassing all of these were identified from a broad range of literature. The understanding of responses to demands within contexts was adapted to identify generic engineering competencies that were required for all engineering jobs. It was expected that generic engineering competencies would exist in inter-related constellations with relative importance that varied across engineering jobs because the tasks and work contexts of the jobs create the demands and the context for the competencies. Ratings of the importance of competencies for engineering jobs were collected along with data about the tasks and work contexts of the engineering jobs, to identify the relationship between these, which was expected based on the DeSeCo framework. The statistical method used to analyse the results allowed for competency factors to be correlated to accommodate the inter-related nature of competencies described by the DeSeCo framework.

Method

The project identified generic engineering competencies required by engineers graduating in Australia. A list of competencies was identified and reduced to sixty four items expected to be generic engineering competencies, based on a literature review.

In Survey 1, these were rated by 300 established engineers, that is, engineers with five to twenty years of experience, for importance to performing their jobs well (Male, Bush, & Chapman, 2009). Data about the engineers' jobs were also collected, because they were expected to be significant based on the DeSeCo framework. To help identify items for the task inventory included in the survey, a panel session was held. In Survey 2, the competencies were also rated by 250 senior engineers, defined as engineers who had managed or supervised established engineers, for importance to performing a typical engineering job in each senior engineer's area of experience. This confirmed the results of the first survey.

The ratings from Survey 1 were factor analysed to identify correlated items among the 64 competencies. An oblique rotation was used, consistent with the expectation that competencies are inter-related and it would therefore be unrealistic to force the competency factors to be orthogonal. Multivariate analyses of variance (MANOVAs) were used to identify significant relationships between the competency factor scores for importance and characteristics of the engineering jobs, which were expected based on the adapted DeSeCo framework understanding that competencies exist in constellations with various relative importance across contexts or jobs in this study.

A focus group of industry members was held to refine the descriptions of the eleven generic competency factors.

Findings Related to Understanding Generic Engineering Competencies

Theoretical framework

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 MANOVA results revealed variation in the importance of generic engineering competencies across job characteristics: tasks and work contexts. This is consistent with the DeSeCo framework's description of competencies as existing in constellations with relative importance varying across contexts. 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, Silburn, & Birchall, 2006, p.5).

Several steps involving excluding individual competencies were necessary to refine the competency model to achieve discriminant validity among the generic engineering competency factors. This difficulty is consistent with the inter-related nature of competencies that is described by the DeSeCo framework for conceptually understanding competencies (OECD, 2002).

Competencies rated most important

Further findings were that 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, engineering business, and practical engineering skills.

Eleven-factor model

The factor analysis identified an eleven-factor model of the competencies derived statistically rather than conceptually which is the more common approach. This established a concise, comprehensive 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 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 or the Stage 1 Competencies. This will make it easier to use to profile the competencies of graduates and to improve engineering education programs in Australia.

Entrepreneurship

Entrepreneurship was identified as a generic engineering competency factor and is not currently explicitly stipulated as a competency that must be developed by students of accredited engineering programs in Australia. The result supports Radcliffe's (2005), Ferguson's (2006), 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. Therefore, "Entrepreneurship" is recommended as the generic engineering competency factor name.

Technical theory

Applying Technical Theory was identified as a generic engineering competency factor. Of the eleven generic engineering competency factors, it received the lowest mean factor score for importance. However, this could be because engineers are not aware when they are using it. 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,* which was adapted from the accreditation criteria. The discussion revealed that one of the reasons this was essential was to recognise whether a possible solution was physically realistic. A design with water flowing up hill 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 competencies felt innate. Then it would be instantly obvious when a solution was impossible. This would explain engineers not realising when they are using first principles of mathematics, science and engineering theory, and hence the relatively low ratings of importance for these competencies in Survey 1.

Inter-disciplinary competencies

A result of the large scale surveys, which is also supported by comments from the focus group, is that fundamental competencies in disciplines 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. In the focus group, electrical/electronic engineers provided examples to demonstrate the importance of a sound understanding of first principles. One example referred to pumping water and the other referred to gas laws. 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.

Generic competencies in engineering

Further considering the inter-related nature of competencies, this study was designed with a theoretical framework that did not separate competencies that are generic to many types of work from those that are engineering-specific competencies. Although a methodology is likely to identify results that are consistent in nature with the adopted theoretical framework, this was not inevitable because 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 Innovation Factor includes not only problem-solving and creativity but also a systems approach, 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.

Identities

The research has implications about engineers' identities. In the focus group, participants were excited by technical competencies and fundamental science, and a participant declared that one of the reasons that 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.

Similarly, understanding of mathematics, science and engineering theory was seen by focus group participants as critical to gaining respect within the engineering profession. A participant in an early panel session on tasks performed by engineers working in research and development 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, 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.

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 this 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.

Implications

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.

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 this study.

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. Problem 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 identified competencies.

The attitudinal competencies that were identified as important are likely to be developed by example. 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.

Program structure

There is a diverse range of engineering program structures in Australia (Johnston, King, Bradley, & O'Kane, 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 University of Melbourne has changed to a 3+2 structure and the University of Western Australia will change to a similar structure in 2012. 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 this study’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.

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 focus group participants’ perception that competencies in fundamental science, mathematics and technical engineering theory were most critical, 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 inter-related 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: both 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 on generic engineering competencies required by engineers (Male, in press). Therefore teaching methods and learning opportunities that develop generic competencies within an engineering framework are recommended. Problem and project based learning are examples of methods that can achieve this.

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. 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.

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. 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 competencies sufficient status in their teaching and students' learning, and to assess students' demonstration of competencies without bias that under-rates the importance of these competencies.

For Engineering Education Policy Makers

Implications 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 stipulated by Engineers Australia, is supported by the personal, interpersonal, business-related and attitudinal elements among the competencies identified as important by this study.
- The broadly-defined nature of the stipulated competencies, allowing for variation between programs, is supported by the results 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 this study, as discussed above in the implications for engineering educators.
- The eleven-factor generic engineering competency model could be considered as a more useful model, than that currently used for accreditation, due to its discriminant validity.
    - 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. A focus group member noted that a difficulty in engineering is often the lack of diversity within teams.
    - U*sing a systems approach* is not reliably understood and therefore requires additional explanation if it is stipulated in accreditation criteria.
- Engineers Australia's holistic assessment of competencies is further supported by this study, which confirmed the inter-related nature of competencies.
- Engineers Australia's initiatives that highlight leadership, diversity and community service are supported by this study. The 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, and *engineering* business competencies, and engineers have concern for the community, the environment, and workers.

For people with an interest in educational theory

This study 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 inter-related 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 the same for all jobs should be questioned.

Conclusions

This study adapted the DeSeCo conceptual framework for understanding competencies to generic engineering competencies and confirmed that the framework applies to engineering. Generic engineering competencies include attitudinal elements. The identified generic engineering competencies are inter-related. Eleven generic engineering competency factors were identified and their perceived relative importance varies across jobs, as expected based on the DeSeCo framework. There are implications for engineering educators, accreditation of engineering programs in Australia, and generic competency theory.

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