Assessing the Generic Competencies of Engineering Graduates: Preliminary Report from an Ongoing Research Program

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Abstract

The context, curriculum and pedagogies of engineering education in Australia have transformed in the last two decades, particularly since the release of the 1996 *Review of Engineering Education* by the Institution of Engineers Australia (now known as Engineers Australia). As in other countries, Australia has adopted outcomes-based approaches across all levels of its education system. Coupled with recent moves towards the 'benchmarking' of undergraduate degree programs, this has highlighted a need for universities to adopt standardised frameworks in evaluating their program outcomes. Recent moves to address the demands of a 'knowledge society', and to acknowledge the increasingly multi-disciplinary nature of work, have highlighted the need for such frameworks to incorporate both generic and discipline-specific graduate competencies.

This paper presents the conceptual framework of an ongoing research program at The University of Western Australia that focuses on assessing the generic competencies of engineering graduates. The approach taken is discussed, drawing on the notion of 'competencies' introduced by the Organisation for Economic Co-operation and Development[1]. Previous efforts to evaluate the generic competencies of engineers both within Australia and abroad are summarised. The discussion focuses on issues associated with evaluating the 'fit' between engineering education and current workplace demands. The paper concludes by highlighting the complexities of evaluating generic competencies in a systematic and standardised manner, and suggesting avenues for future work within the field.

Background and Motivation

This paper discusses preliminary work on an ongoing research program. The goals of the research program are to extend previous work on identifying the generic competencies required of graduate engineers, and to establish a reliable and valid instrument to assess these competencies in the workplace. The validated instrument will have applications in (i) evaluating and benchmarking Bachelor of Engineering (BE) degree programs, and (ii) establishing a feedback mechanism which assists in linking industry and education and 'closing the loop' in the ongoing development of BE degree programs. In this second application, the instrument could be used to evaluate the efficacy of program changes made in response to shifting industry demands. The measurement of program outcomes is consistent with the ideology of outcomes-based education (OBE).

Over the past three decades, moves towards the globalisation of tertiary industries have prompted a convergence of interest in comparing higher education qualifications on an international basis. Engineering bodies in several countries, including the Accreditation Board for Engineering and Technology (ABET) in the United States and Engineers Australia (EA), have recognized the need to embrace these trends, and have been instrumental in motivating providers of engineering education to respond accordingly. This is apparent in the current accreditation criteria imposed by ABET and EA, which require universities to demonstrate that their Bachelor of Engineering programs develop a number of generic attributes that are deemed to be desirable in engineering graduates.

The specific impetus for the current program arose in a 2003 meeting of The University of Western Australia (UWA) Engineering Advisory Board. This Board includes both industry and academic representatives. At that time, the Board expressed a desire to elaborate further the framework used to assess the generic competencies of UWA engineering graduates. Several questions arose with respect to the notion of 'outcomes' needed of university engineering education today. Questions asked, for example, which outcomes to measure and how to measure them.

Method: The Research Program Framework

Phase I. Preparatory Development Work

A review of previous work has advised the development of the research program framework outlined here. Key results of this review, which were significant in the development of the research framework, are discussed under the heading 'Results' below. Further, ongoing reviews of previous work are identifying a comprehensive set of graduate competencies from which the set to be used will be selected. While sets of graduate competencies have been identified by EA[2] and in other previous studies noted below, the current research program will extend on previous work by integrating material from a broad range of sources, both local and international. Phase I and II of the current program will apply the findings of previous work in a quantitative study of the generic competencies of graduate engineers. The primary purpose of the study is to provide results which can be generalised at least nationally.

Phase II. Preliminary Content Validation

Phase II will determine indicators of aptitude in graduates to develop the generic competencies of successful engineers. This will be achieved by: (i) confirming the roles performed by engineers, and whether these can be classified as general or specific to roles or employment types, (ii) determining competencies required to perform those roles, (iii) determining indicators, in graduates, of aptitude to develop these competencies, and (iv) describing behaviours for various levels of strength in each indicator of aptitude.

To confirm the roles performed by engineers, findings of qualitative research conducted by Trevelyan[3] and colleagues will be used. These provide detailed descriptions of approximately eighty roles performed by engineers. Examples of roles are 'conduct research into standards' and 'predict failure modes'. In the current research the list of roles from Trevelyan's work will be condensed and used as the basis for a large scale survey of the roles performed by established engineers and competencies required in these roles. Participants in this survey will be asked to rate the importance to their position of each role listed and of each competency listed.

Graduate indicators, which demonstrate aptitude for development of the competencies identified in this first survey, will be derived. These will be considered in panel sessions with senior engineers and industry representatives, senior engineering academics and people with experience in graduate development. Anchors will be derived to represent different levels of strength for each indicator.

Phase III. Instrument Development

As discussed below, several studies have interviewed and/or surveyed employers, graduates, students and/or supervisors to identify the competencies required of graduates in industry[4-11].

The survey instrument will be implemented online. The instrument will be designed to be completed independently and confidentially by (i) two engineers who have supervised the same graduate, for at least 1 month, not necessarily simultaneously and (ii) the graduate.

The instrument will incorporate a response format for each indicator, which allows supervisors to indicate levels of attainment of the competencies. These anchors will 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 (e.g., frequency, intensity, consistency) will be considered. This will increase the standardisation of ratings across supervisors and thus the reliability, and applicability of the instrument across contexts.

Phase IV. Initial Validation

Initially, the survey instrument will be tested with approximately 15 supervisors of engineering graduates and 7 graduates. Multiple supervisors for one graduate will 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 will be generated to produce 'error bands'. These estimates will be used in two ways. For items in which the errors are large, efforts will be made to identify the cause of this, and to further clarify or more finely operationalise the items (i.e. express the item at a higher degree of specificity). In cases where the band is within acceptable limits, these will be used to define the level of precision achievable in the ratings.

Phase V. Large-Scale Validation

The final instrument will be completed by a large sample ($n > 200$) of pairs of supervisors of engineering graduates and at least as many graduates.

Phase VI. Test-Retest Data

A small group ($n = 30$) of supervisors and at least as many graduates, will be invited to complete the survey again within 8 weeks of completing the initial survey. Any items that demonstrate significant variance across the two time points will 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.

Phase VII. Analysis, Final Validation, and Refinement

The data collected will be analysed using traditional reliability estimates, assessments of construct and criterion related validity, and factor and item analysis. Subgroups of graduates will be formed according to (i) the subdiscipline area in which the graduate has worked, and (ii) the demographic variables recorded (e.g., males vs females). Competency profiles will be developed for students from different subgroups.

Results of Phase I: Current Tre nds, Previous Work, Issues and Complications

Early work on the project has revealed issues and complications in measuring the generic competencies of engineering graduates. Questions that have arisen include: What are competencies? Which competencies are generic? In answering these questions, previous work was considered.

Current Trends in Higher Education

The Organisation for Economic Cooperation and Development (OECD) produced a report in 2004[12] which highlighted the need for its member countries to "establish international frameworks for quality assurance across borders" (p.9), and to "facilitate fair and transparent recognition for foreign qualifications" (p.11). This report also posed that the evaluation of university qualifications should focus on comparing the learning outcomes or competencies of program graduates, rather than attempting to compare programs on the basis of unit outlines or curriculum materials:

> 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 (p.12).

The OECD defined a "competency" as "the ability to successfully meet complex demands in a particular context"[1] (p.2). In an earlier OECD report[13], "key competencies" were defined as those that are "important across multiple areas of life, and contribute to an overall successful life and a well-functioning society (p.10). These were contrasted with "domain-specific" competencies, which "do not apply across multiple areas of life, are not necessary for everyone…or are irrelevant to the betterment of individual and societal life" (p.10).

Despite this distinction, recent shifts in workplace demands have prompted interest in exploring key competencies *within specific domains*. That is, efforts are being made to identify competencies that are *necessary for everyone within a particular discipline area*. Applying this to the field of engineering, and drawing from the OECD framework, these would include 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. This will be the focus of the work proposed here.

There is considerable inconsistency in the use of terms within this field. For example, the term 'key competencies' is often used interchangeably with the terms 'generic competencies' or 'generic attributes'[14]. The term 'generic competency' is used with the same meaning as "key competency" in this paper. Recent research at the University of Sydney[15] also indicated that academics in different disciplines have different conceptions of graduate attributes.

As noted above, generic competencies must be relevant across all areas of a particular discipline. Thus, competencies such as communication, problem-solving, and self-directed learning are often cited in the generic competencies literature. As noted by Scardamalia and Berieter[16], in the current 'knowledge society', knowledge changes constantly and rapidly, placing a heavier emphasis on the need for generic, process-oriented competencies (e.g., resourcefulness, self-regulation) in addition to static or discipline-specific knowledge:

> when asked about the kinds of skills that the younger generation need to advance in the workplace, typical answers include such characteristics as flexibility, creativity, problem-solving ability, technological literacy, information-finding skills, and a lifelong readiness to learn (p.32).

This comment suggests that, in order to succeed in their post-training placements, graduates need to be flexible, fluent, and resourceful, have the competencies required to communicate effectively with people from various backgrounds, and be able to transfer their competencies readily across contexts. By implication, undergraduate programs need to prepare candidates for a range of multi-disciplinary jobs, and equip them with the competencies required to adapt readily to change. These trends have highlighted a need for such programs to include a clear emphasis on developing students' life-long learning competencies, and promoting their engagement with broader social, ecological, and economic issues.

The OECD made a further contribution to scholarship in this field by establishing a framework for identifying generic competencies required by everyone. This was a product of their program on the *Definition and Selection of Competencies* (*DeSeCo*), conducted from 1998 to 2002. The purpose of this program, as outlined in the *DeSeCo Strategy Paper*[13], 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...[and] to establish a reference point for interpreting empirical results in relation to the outcomes of learning and teaching (p.6).

Parts of the *DeSeCo* framework are adopted in the current research. The framework describes competencies as[17]:

> 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 (p.48).

The planned instrument which asks supervisors to rate competencies of graduates is consistent with this concept. The *DeSeCo* framework recognises that levels of achievement of possession of a competency exist on a continuum[13]. This is reflected in the current research framework in the use of rating scales with anchors for different levels of attainment.

Current Trends in Engineering Education

International trends in engineering education have been consistent with general moves to establish standardised frameworks for comparing educational qualifications[18], and to develop competency frameworks that facilitate the international mobility of graduates[19, 20]. Consistent with the conclusions of the OECD[13] report, learning outcome criteria have been identified as a key means by which such frameworks can be disseminated across systems. As in other areas of higher education, there has also been an increasing concern in engineering education to ensure that graduates possess the generic competencies required for workplace success, including both technical and non-technical components.

In Australia, programs leading to a Bachelor of Engineering award are accredited by EA. EA adopted its own definition of a generic competency in its *National Generic Competency Standards for Stage 2,* the stage one level above the graduate level. These Standards defined a competency as[21] "the ability to perform activities in an occupational category or function to the standard expected in employment" (p.4).

While this definition is similar in its orientation to the OECD key competencies framework, it is more restrictive. In particular, it defines the competencies of engineers only in terms of those required to meet employment expectations. While the primary concern of accreditation organisations must be to ensure that only suitably competent people are given the opportunity to practice engineering, the responsibility of engineering education providers is broader. Universities have a responsibility to educate graduates to be responsible citizens, taking initiative beyond the requirements of their employment[22]. Levy and Murnane[23] note for example 'compassion' and 'empathy', which are important to the survival of society, and are not necessarily important to a graduate's employment. In this light, it will be useful to apply the OECD framework for 'key competencies' to the engineering profession. In doing this, the assumption made will be that the competencies of engineering graduates should not only include those that are consistent with workplace expectations, but also those that facilitate the success of the individual or his/her contribution to society as a member of the engineering profession. The latter two forms of competencies are not emphasised in the EA definition, though the first tenet of the Code of Ethics of EA gives community first priority[24].

As early as 1955, the *Evaluation of Engineering Committee of the American Society for Engineering Education* (ASEE) paper[25] cited reports from the 1940s which called for 20% of engineering education to reside within the "humanistic-social stem" (p.58). This paper 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 paper reiterated these needs, and highlighted a further need for programs to include "the development of a high level of performance [in communication]" (p.25). More recent reviews of engineering education in Australia[26, 27] and the U.S. indicate that concerns for developing the generic competencies of engineers remain current[28]. These reviews identified attributes such as competency in communication, and engagement with the broader social, environmental and economic issues of society as necessary. Thus, although the definition of 'competency' used by EA is relatively restrictive, many of the viewpoints expressed elsewhere and in the IEAust review are well aligned both with the OECD framework and the notion of generic competencies adopted here. Further, in its accreditation criteria, EA identifies 10 generic attributes[29], some of which are well aligned with these broader notions. The EA criteria stipulate that graduates of accredited programs should exhibit the following attributes:

(i) ability to apply knowledge of basic science and engineering fundamentals;
(ii) ability to communicate effectively, not only with engineers but also with the community at large;
(iii) in-depth technical competence in at least one engineering discipline;
(iv) ability to undertake problem identification, formulation and solution;
(v) ability to utilise a systems approach to design and operational performance;
(vi) ability to function 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;
(vii) understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;
(viii) understanding of the principles of sustainable design and development;
(ix) understanding of professional and ethical responsibilities and commitment to them; and
(x) expectation of the need to undertake lifelong learning, and a capacity to do so. (pp. 7-8.)

Again, therefore, while the definition of 'competency' offered by EA does not acknowledge explicitly the importance of competencies that relate to the engineer as an individual and as a member of society, their importance has been recognized.

Previous Research on Evaluating the Generic Competencies of Engineers

Criterion 3 of the ABET *Criteria for Accrediting Engineering Programs*[30] , lists eleven program outcomes that map to abilities and knowledge that graduates of engineering programs are expected to have. This document stipulates that "There must be … an assessment process…that demonstrates that these program outcomes are being measured…" (p.2). As a result, considerable literature exists on methods of operationalising and assessing program outcomes according to such criteria[31-33]. This literature, however, focuses largely on measuring graduate outcomes prior to workforce entry.

Other studies have focussed on evaluating education programs and the 'fit' between industry demands and education outcomes. For example, in a study involving machine engineering factories from Bavaria and Baden-Württemberg[34], employees were presented with a list of competencies needed by design engineers. These included specific knowledge areas (e.g., knowledge of PC standard software).

Two studies in the US assessed the generic competencies of engineers for the purpose of identifying 'gaps' in undergraduate training programs. In the first[35], 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. 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. The second[8] identified 54 engineering competencies grouped into broad categories, which included technology, communication, and teaming.

Three studies have appeared in which the generic competencies of engineers have been examined in Australia. One study[36] asked academic staff, HR staff, senior engineering staff, and graduates from RMIT to evaluate the extent to which their program developed each of 27 generic competencies. These were broadly consistent with the 10 competencies specified by EA, with an additional 17 including subsets of the original 10 (e.g., communication skills were listed, but writing and listening skills were also listed separately). More recently in Australia[37], 215 employers and 508 engineering graduates in Tasmania were asked to assess the extent to which their program developed the 10 EA generic attributes. In the third study[10], a list of 49 relevant competencies were identified across six categories (emotional intelligence – personal; emotional intelligence – interpersonal; intellectual capability; profession-specific skills and knowledge; generic skills and knowledge, and educational quality).

Discussion of Results and their Significance

The studies conducted thus far indicate the level of international demand for establishing competency frameworks within the field. These studies have contributed significantly to identifying the types of competencies that may be relevant. Many of these have, however, measured outcomes relevant to specific universities, specific locations (i.e., using national accreditation criteria) or specific industry groups (e.g., software engineering).

The goals of the research program discussed here will be to extend on previous studies by establishing an instrument which assesses specific defined graduate competencies that are relevant across multiple contexts. The research program will apply results of previous studies to develop an instrument for identifying the generic competencies of engineers. Unlike previous studies, the framework used will adopt the OECD concept of 'competency', acknowledging the need identified by the DeSeCo project for everyone to have competencies which facilitate their individual success and their contribution to the well-functioning of society.

Conclusions and Recommendations

This paper presents the framework for an ongoing research program to develop a survey instrument to measure the generic competencies of engineering graduates. Several previous studies have identified and measured competencies required by engineers in specific disciplines and in specific locations or specific industry groups. This research program will extend on such work assessing graduate competencies that are more broadly relevant.

The term 'competency' itself has been ambiguous and has been used interchangeably with other terms. The recent OECD DeSeCo project recognised the need to resolve this problem and provide a more systematic approach to measuring these educational outcomes. The present research will contribute to the field by applying these notions within engineering.

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