Identification of competencies required by engineers graduating in Australia

Sally A Male
The University of Western Australia, Perth, Australia
sallymale@mech.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**: To inform continuous improvement of engineering education, this study asks, "What are the generic engineering competencies that engineers graduating in Australia require?" Competencies that were likely to be important to engineering work were identified from a broad range of literature. These were rated by 300 "established engineers" for importance to doing their jobs well. The study is the first large scale quantitative Australian study, across all engineering disciplines, to focus on established engineers rather than graduates. The engineers perceived technical, non-technical and attitudinal competencies as important. This is consistent with large scale studies in the US and Europe, and small scale studies in Australia. The results support continued expansion of curricula and diversification of pedagogies.*

Introduction

Engineers are necessary for nations' economies, and for the design, development and maintenance of infrastructure and technology to sustainably satisfy communities' needs and lifestyles. The authors take the viewpoint that engineering educators have a responsibility to society and to engineering students to develop in students the competencies that graduates will need to become established engineers. In recent decades engineering curricula, largely influenced by program accreditation requirements, have expanded beyond traditional technical learning areas. To inform continuous improvement of engineering education, this study asks, "What are the generic engineering competencies that engineers graduating in Australia require?" These competencies are defined as those that are important across all areas of engineering, and facilitate the success of engineers as individuals doing their jobs well. This paper presents the identified competency items and their importance as perceived by established engineers.

Theoretical framework and methodology

To establish clarity and consistency with an agreed practical theoretical framework, this study used the conceptual framework for competencies developed by a multidisciplinary international project (OECD, 2002). In the framework competencies can be observed as responses to demands within contexts. Consistent with the framework, this study focused on performance in the workplace as the context, and competencies were understood to be interdependent, and to include a combination of knowledge, skills, attitudes and dispositions.

This study was initiated by, and received advice from, an Industry Advisory Committee consisting of five senior engineers from small and large organizations across a diverse range of industries. Members agreed that it is more often important that engineering graduates are able to develop into effective engineers, than to be effective graduates. Therefore, the study identified the competencies that are perceived to be important by "established engineers" to do their jobs well. Established engineers were defined as those with 5 to 20 years of experience since graduating from an engineering degree of at least 4 years.

Previous studies on competencies required by engineers

Previous studies include those to develop accreditation criteria (EA, 2005, ABET, 2008, ENAEE, 2008), large quantitative studies outside Australia (Meier *et al.*, 2000, Bodmer *et al.*, 2002, Brumm *et al.*, 2006, Spinks *et al.*, 2006), and relatively small scale studies within Australia (Nguyen, 1998, Scott and Yates, 2002, Ferguson, 2006, Nair *et al.*, 2009). It could not be assumed that international results generalise to the Australian context. Therefore a large scale Australian study was needed.

Method

Competencies that were likely to be important to engineering work were identified from a broad range of literature in the fields of engineering education, higher education, and key competencies. Significant sources included the Stage 1 Competencies (EA, 2005a), generic attributes (EA, 2005b), and studies by Gill *et al.* (2005), Trevelyan (2007), Sorby and Baartmans (2000) and Otieno (2006). Identified items were refined to a list of 64 competencies. In a survey, established engineers rated each competency for importance to doing their jobs well, on a 5-point scale (1 = *not needed*; 5 = *critical*).

Table 1: Demographics of engineers who participated in survey

Demographic variable and values	*Responses*	*Responses as % of responses to question*
Location where participant worked		
Western Australia	226	75
Australia, excluding Western Australia	38	13
Outside Australia	36	12
University that awarded participant's undergraduate engineering qualification		
The University of Western Australia	217	72
Other	83	28
Gender		
Male	245	82
Female	55	18
Engineering discipline in which participant was qualified		
Mechanical/aeronautical/materials/mechatronics/ metallurgical/naval architecture/chemical	111	37
Civil/structural/environmental/geotechnical/mining	96	32
Computer systems/electrical/electronic/ communications/software/IT	92	31
Size of organization in which participant was employed		
0-50	51	17
51-500	46	15
Over 500	203	70

Participants were recruited through letters to engineering graduates, and calls for volunteers through Engineers Australia (EA), and industry advisory groups in the faculty. Usable responses were received from three hundred engineers. Participant demographics are shown in Table 1. Some demographic questions were adapted from a remuneration survey conducted by the Association of Professional Engineers, Scientists and Managers Australia (APESMA) and EA (2005). Participants' key responsibilities were similar to those of participants in the Autumn 2007 Professional Engineer Remuneration Survey (D. Angerame, APESMA, personal communication, June 27, 2007). Industry

representation was similar to national APESMA/EA data, except that the mining and the oil and gas industries resembled the higher Western Australian figures (*ibid.*). Industries represented by the highest percentages of participants were consulting/technical services (37%), construction/contract/ maintenance (23%), mining/quarrying (28%) and oil/gas exploration/production (17%).

The high portion of responses from Western Australia is a limitation of the study. Results can be assumed to generalise to a state such as Queensland with similar industries to Western Australia. However, the similarity of key responsibilities to those of participants in the national APESMA/EA remuneration survey implies that the results could generalise nationally.

Results and analysis

Each competency in the survey was rated as critical by at least 14 (4.7%) of the participants and all but three of the competency items were rated 3 or higher by at least 50.3% of the participants. The competencies rated as critical by over 50% of the survey participants, can be summarized as communication, teamwork, self-management and problem solving, and are all competencies related to EA generic graduate attributes and rated as highly important in previous studies (Table 2).

Table 2: Generic engineering competencies identified as important to engineers

Competency	*Competency as Identified in Questionnaire*	*Mean Importance (1=not needed; 5=critical)*	*SD*	*N*
Written comm.	Communicating clearly and concisely in writing (e.g. writing technical documents, instructions, specifications)	4.54	0.67	300
Managing comm.	Managing own communications (e.g. keeping up to date and complete, following up)	4.49	0.61	300
Self-management	Managing self (e.g. time/priorities / quality of output / motivation/efficiency/emotions / work-life balance/health)	4.49	0.66	300
Verbal comm.	Using effective verbal communication (e.g. giving instructions, asking for information, listening)	4.48	0.64	300
Teamwork	Working in teams (e.g. working in a manner that is consistent with working in a team / trusting and respecting other team-members / managing conflict / building team cohesion)	4.46	0.76	300
English	Speaking and writing fluent English	4.45	0.68	300
Interdisc. skills	Interacting with people in diverse disciplines/professions/trades	4.42	0.80	300
Commitment	Being committed to doing your best	4.40	0.67	300
Problem-solving	Solving problems (e.g. defining problems, analysing problems, interpreting information, transferring concepts, integrating disciplines, thinking conceptually, evaluating alternatives, balancing trade-offs)	4.39	0.79	298
Honesty	Demonstrating honesty (e.g. admitting one's mistakes, giving directors bad news)	4.38	0.71	300
Decision-making	Making decisions within time and knowledge constraints	4.33	0.78	299
Self- motivation	Being positive/enthusiastic/motivated	4.29	0.66	300
Practical	Demonstrating practical engineering knowledge and skills and familiarity with techniques, tools, materials, devices and systems in your discipline of engineering (e.g. ability to recognise unrealistic results)	4.28	0.82	300
Sourcing info	Sourcing/understanding/evaluating information <em(e.g. from co-workers/colleagues/documents/observations)	4.24	0.80	300
Ethics	Acting within exemplary ethical standards	4.22	0.88	300
Demeanour	Presenting a professional image (i.e. demeanour and dress) (e.g. being confident/respectful)	4.17	0.79	299
Managing	Managing (e.g projects/programs/contracts/people/strategic planning/performance/change)	4.17	1.00	296
Critical thinking	Thinking critically to identify potential possibilities for improvements	4.17	0.75	300

Graphical comm.	Using effective graphical communication (e.g. reading drawings)	4.16	0.85	299
Flexibility	Being flexible/adaptable / willing to engage with uncertainty or ill-defined problems	4.14	0.78	299
Creativity	Thinking laterally / using creativity/initiative/ingenuity	4.03	0.79	300
Concern for others	Being concerned for the welfare of others in your organization (e.g. voluntarily sharing information, ensuring decisions are fair, facilitating their contribution)	4.01	0.87	300
Negotiation	Negotiating / asserting/defending approaches/needs	4.00	0.85	300
Info-management	Managing information/documents	3.99	0.86	299
Action orientation	Having an action orientation (e.g. avoiding delays, maintaining a sense of urgency)	3.97	0.82	300
Coordinating	Coordinating the work of others	3.91	1.08	300
Meeting skills	Chairing / participating constructively in meetings (e.g. team meetings / fora/workshops / focus groups / interviews)	3.86	1.00	300
Loyalty	Being loyal to your organization (e.g. representing it positively)	3.86	0.91	300
Managing development	Managing personal and professional development (e.g. self-directed/independent learning; learning from advice/feedback/experience; thinking reflectively and reflexively)	3.85	0.88	299
Presenting	Presenting clearly and engagingly (e.g. speaking, lecturing)	3.84	1.00	300
Diversity skills	Interacting with people from diverse cultures/backgrounds	3.83	1.09	300
Networking	Networking (i.e. building/maintaining personal/organizational networks)	3.75	1.03	300
Reliability	Evaluating reliability / potential failures	3.74	1.18	298
Design	Using design methodology (e.g. taking the following steps: defining needs, planning, managing, information gathering, generating ideas, modelling, checking feasibility, evaluating, implementing, communicating, documenting, iterating)	3.74	1.14	298
Liability	Applying familiarity with risk/liability/legislation/standards/codes / IP issues	3.71	1.03	300
Leading	Leading (e.g. recruiting team members / gaining cooperation / motivating and inspiring others / influencing/persuading others)	3.71	1.12	300
Life-cycle	Being familiar with complete life-cycle of projects/programs/products	3.67	1.06	300
Supervising	Supervising work/people	3.65	1.10	300
Focus	Focusing on your organization's needs	3.64	1.03	300
Embracing change	Trying new approaches/technology / capitalising on change / initiating/driving change	3.64	0.93	298
Cross-fn familiarity	Applying familiarity with the different functions in your organization and how these interrelate	3.52	1.00	299
Mentoring	Mentoring/coaching co-workers	3.51	1.03	300
Maintainability	Evaluating / advocating for / improving maintainability	3.46	1.16	300
Risk- taking	Taking considered risks	3.46	1.06	299
Keeping up to date	Keeping up to date with current events / contemporary business concepts / engineering research/techniques/materials	3.41	1.03	300
Theory	Applying mathematics, science or technical engineering theory or working from first principles	3.30	1.21	299
Workplace politics	Understanding social and political dimensions of workplaces	3.30	1.12	298
Safety	Evaluating / advocating for / improving health and safety issues	3.26	1.26	300
Community	Being concerned for the welfare of the local, national and global communities	3.20	1.17	300
Generalisation	Generalising/abstracting concepts	3.19	1.10	299
Systems	Using a systems approach	3.16	1.16	299
Sustainability	Evaluating / advocating for / improving sustainability and the environmental impact (local/global) of engineering solutions	3.11	1.26	299
Modelling	Modelling/simulating/prototyping and recognising the limitations involved	3.11	1.26	299

Integrated design	Using 'simultaneous engineering design and development' / 'integrated product and process design' / 'collaborative engineering'	2.94	1.15	299
Marketing	Evaluating marketing issues / applying a customer focus	2.89	1.29	300
Aesthetics	Appreciating aesthetic features of design	2.75	1.21	300
Social context	Evaluating the impact of engineering solutions in the social/cultural/political contexts (local/global)	2.73	1.20	298
Entrepreneurship	Engaging in entrepreneurship / innovation / identifying and commercialising opportunities	2.72	1.15	300
3D skills	Using 3D spatial perception or visualisation (e.g. visualising various perspectives)	2.68	1.32	300
Research	Using research / experimentation techniques / scientific method	2.66	1.26	300
Manufactur-ability	Evaluating / advocating for / improving manufacturability	2.61	1.29	300
Promoting diversity	Actively promoting diversity within your organization (e.g. culture, religion)	2.46	1.20	300
Citizenship	Engaging in active citizenship (e.g. being involved in the local / national or international community / engaging in public debates)	2.36	1.15	300

Discussion and implications

The established engineers rated technical, non-technical and attitudinal competencies as important. These results are consistent with large scale studies in the USA and Europe, and small scale studies in Australia. The results support the continued expansion of curricula and diversification of pedagogies, such as have begun in recent decades, to develop competencies beyond the purely technical.

Of the competencies with a mean rating above 4, *problem-solving* and *practical engineering* are the only technical items. *Design*, *theory* and *research* received lower mean ratings. These competencies have been central to engineering curricula. This study does not question their necessity. However, the results strongly support the conclusion of Newport and Elms (1997), that technical competencies are not sufficient for success as an engineer.

Communication, teamwork, professional attitudes, business skills, problem solving, critical thinking creativity, and practical skills were perceived as highly important. Such competencies are unlikely to be developed through traditional teaching methods. The result implies that non-traditional methods such as problem and project based learning, and non-traditional assessment methods, are required.

Generic engineering competencies that are identified by this study and are not clearly included in the EA graduate attributes are related to understanding the workplace, and entrepreneurship. This was also identified as additionally required by Ferguson (2006).

Competencies that featured in the literature but received relatively low ratings of importance included *safety*, *community*, *sustainability* and *social context*. The importance of these competencies would probably be highlighted by methods other than used by this study. Either a general question about whether these competencies are important for engineering graduates, or a survey of a different group of stakeholders, would be likely to glean higher ratings for these competencies.

Conclusion

This study identified 64 generic engineering competencies required by engineers graduating in Australia. Results were consistent with large scale studies in the USA and Europe. Technical, non-technical and attitudinal competencies were identified as important. Communication, teamwork, self-management and problem solving were perceived as critical by the highest percentage of the engineers.

References

APESMA & EA (2005). Spring 2005 Professional Engineer Remuneration Survey.

EA (2005a). *Engineers Australia national generic competency standards - stage 1 competency standards for professional engineers.* Canberra: Engineers Australia, P05.

EA (2005b). *Engineers Australia policy on accreditation of professional engineering programs.* Canberra: Engineers Australia, P02.

Ferguson, C. (2006). *Attributes for Australian mechanical engineers through proximal and distance education*. Thesis (Doctor of Technology). Deakin University.

Gill, J., Mills, J., Sharp, R. & Franzway, S. (2005). Education beyond technical competence: Gender issues in the working lives of engineers. *In*: D. Radcliffe & J. Humphries, eds. *Proceedings of 4th ASEE / AaeE Global Colloquium on Engineering Education*) Sydney: American Society for Engineering Education.

Newport, C.L. & Elms, D.G. (1997). Effective engineers. *International Journal of Engineering Education,* 13 (5), 325-332.

OECD (2002). *Definition and selection of competencies (DeSeCo) theoretical and conceptual foundations: Strategy paper*: Organisation for Economic Co-Operation and Development.

Otieno, A., Azad, A. & Balamuralikrishna, R. (2006). Creating a bridge to simulate simultaneous engineering experiences for senior undergraduate students. *European Journal of Engineering Education,* 31 (2), 181 - 189.

Sorby, S.A. & Baartmans, B.J. (2000). The development and assessment of a course for enhancing the 3-d spatial visualization skills of first year engineering students. *Journal of Engineering Education,* 89 (3), 301-307.

Trevelyan, J.P. (2007). Technical coordination in engineering practice. *Journal of Engineering Education,* 96 (3), 191-204.

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