Taxonomies of Engineering Competencies and Quality Assurance in Engineering Education

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Abstract This chapter reviews both literature and theory related to the identification and articulation of graduate attributes and competencies that are relevant to engineering education. Such attributes and competencies form the basis for Quality Assurance in engineering education. This chapter includes but looks beyond the sources that are normally reviewed in creating statements on graduate attributes. The review was part of the work done in developing the taxonomy of engineering competencies. Given its somewhat unique genesis, context, and perspective, this particular taxonomy provides an interesting case study of how literature, theory, and research-based evidence can be combined to form statements of graduate attributes for a specific educational discipline.

Introduction

The general impetus which motivated the development of the taxonomy of engineering competencies described in this chapter was the societal change in South Africa after the demise of Apartheid. This change led to educational *massification* and the typical problems associated with it – under-prepared students, large classes, and a diverse first year intake all of which contributed to substantial attrition and academic failure.

In describing the development of the taxonomy of engineering competencies – hereafter referred to simply as the *taxonomy* – the chapter is divided into three parts. Part 1 begins with a brief review of the concepts of quality and curriculum responsiveness. This provides a theory-based position for identifying the stakeholders in engineering education and their concerns. Following this, attention is given to the

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important issue of what is understood by the term *competency*. A review of the literature relating to engineering competencies constitutes Part 2 of the chapter. It includes listings of graduate competencies and attributes that are considered relevant and significant to an articulation of the goals of engineering education. The review is based on the literature search carried out during the development of the *taxonomy*. To bring the review up to date, literature and taxonomies that have emerged since the *taxonomy* was formulated in 2002 are also discussed in Part 2. Part 3 presents the *taxonomy* and describes its development as a case study that draws on the principles in Part 1 and the information gleaned from literature that is presented in Part 2.

Part 1: Some Preliminaries – Quality and Competency

Identifying the Stakeholders in Engineering Education

Quality is a complex trait. It includes not only a judgment of the extent to which a product or service meets a range of expectations, and is free of defects, but also how a customer experiences the product or service, both in part and as a whole (Sinha and Willborn 1985, p. 4). To define quality, therefore, one must identify the expectations of customers regarding the performance of the products or services they receive.

But, in the sphere of higher education, what do we mean by *customer*? To answer this question, it is helpful to begin with the concept of *curriculum responsiveness*. This is the idea that a curriculum (the educational program as a whole[1]) must be appropriately *responsive* to the legitimate expectations, requirements, and interests of stakeholders regarding how the program functions and what it delivers. Moll (2004), in synthesizing relevant theory, distinguishes between the following four kinds of curriculum responsiveness and, in doing so, identifies the four primary *stakeholders* in higher education.

1. *Economic responsiveness*. This has to do with how the curriculum "is responsive to the prevailing labor market by incorporating the necessary high level qualifications, knowledge and skills demanded by a modern, diversified economy" (p. 4). Here the *stakeholders* of engineering education are the economy and the labor market.
2. *Disciplinary responsiveness*. This has to do with how the curriculum "is responsive to the nature of its underlying discipline by ensuring a close coupling between the way in which knowledge is produced and the way students are educated in

[1]"*Curriculum* comprises all the opportunities for learning provided by an educational institution. These include the formal program of lessons in the timetable and the climate of relationships, attitudes and styles of behavior promoted within the institution as a whole" (Department of Education and Science for England and Wales, 1980, in Simelane 2006, p.32).

the discipline area" (p. 5). Here the *stakeholder* is the discipline – engineering in general and/or a particular branch of engineering.

3. *Cultural/Societal responsiveness*. This has to do with how the curriculum "is responsive to the cultural diversity of students and society by incorporating multiple cultural reference points that acknowledge diversity and constitute various alternative learning pathways for students" (p. 7). Here the *stakeholder* is society at large.
4. *Learner responsiveness*. This has to do with how the curriculum "is responsive to the learning needs of students by teaching them in terms that are accessible to them and assessing them in ways that they can understand" (p. 8). Here the *stakeholder* is the student.

Responsiveness: The Provision of Quality Educational Programs

Accreditation standards used by professional engineering bodies relate directly to economic and disciplinary responsiveness: standards are used with the intention of making sure that graduates from accredited programs have the knowledge, skills, and dispositions (values/attitudes/commitments) demanded by the labor market and are competent to participate in and contribute as professionals to the practice of a particular branch of engineering.

In regard to the nature of societal and learner responsiveness, the South African context provides interesting examples. After the demise of Apartheid, considerable political transformation has taken place in which the issue of education has been key. A particularly pressing problem was how to restructure educational systems so that they address the very significant shift that occurred in the demographics and educational backgrounds of entrants to higher education. Learner responsiveness was a major concern here because of the very high levels of student *under-preparedness* for higher education programs (Pinto 2001; Woollacott et al. 2003). In response to this concern, a national policy was created to guide the South African educational restructuring effort.

The following list is an extract from a bulletin of the South African Qualifications Authority (SAQA) (South African Qualifications Authority 1997, p. 8). The extract spells out the general, nontechnical or core competencies – termed critical cross-field outcomes – which any educational program in South Africa is required to develop in learners. The last item in the list expresses very clearly the concern that an educational program should facilitate both professional and personal development since both the provision of suitably qualified professionals and the personal change attained through their educational experience have a positive impact on and enrich society. The Minster of Education put it this way, an educational program should facilitate the development in graduates of "intellectual capabilities and skills that can both enrich society and empower themselves and enhance economic and social development" graduates should be able to: (Department of Education 2007, p. 3).

1. Identify and solve problems in which responses display that responsible decisions using critical and creative thinking have been made.
2. Work effectively with others as a member of a team, group, organisation or community.
3. Organise and manage oneself and one's activities responsibly and effectively.
4. Collect, analyze, organise and critically evaluate information.
5. Communicate effectively using visual, mathematical and/or language skills in the modes of oral and/or written presentation.
6. Use science and technology effectively and critically, showing responsibility towards the environment and health of others.
7. Demonstrate an understanding of the world as a set of related systems by recognising that problem-solving contexts do not exist in isolation.
8. To contribute to the full personal development of each learner and the social and economic development of society at large, it must be the intention underlying any program of learning to make an individual aware of the importance of:

– Reflecting on and exploring a variety of strategies to learn more effectively
– Participating as responsible citizens in the life of local, national and global communities
– Being culturally and esthetically sensitive across a range of social contexts
– Exploring education and career opportunities
– Developing entrepreneurship

Cultural/societal, economic, and disciplinary responsiveness are made more explicit in a second extract from South African government policy documents (South African Qualifications Authority 2000, p. 14) which states that an educational program should:

- provide benefits to society and the economy through enhancing citizenship, increasing social and economic productivity, providing specifically skilled/professional people and transforming and redressing legacies of inequity;
- add value to qualifying learners in terms of enrichment of the person through the provision of status, recognition, credentials, and licensing, marketability and employability; and the opening-up of access routes to additional education and training.

These extracts imply that educational programs should aim to satisfy the legitimate expectations of all four groups of stakeholders simultaneously.

Competency and Graduate Attributes

In simple terms, *competence* means "having the necessary skill or knowledge to do something successfully" and comes from the Latin *competere* "to be fit or proper" (Compact Oxford English Dictionary on AskOxford.com). As applied to professionals such as engineers it conveys the idea of possessing sufficiently the capability, skill, aptitude, proficiency, and expertise required to perform professional duties effectively. A more rigorous definition sees competency as "an underlying characteristic of an individual that is causally related to (causes or predicts) criterion-referenced effective and/or superior performance in a job or situation" (Spencer and Spencer 1993, p. 9). It is important to recognize that the criteria used to assess the level of competence are closely linked to the characteristic of the product or service to be provided, that is, the intended consequences of the task(s) that are performed. This link is brought out very clearly in the definition of competency that sees it as the ability to produce intended consequences without creating unintended consequences (Argyris and Schon 1974, pp. 6, 29). Passow (2007, p. 1) pulls these ideas together well in her definition of *competencies* as:

> the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action) in complex and uncertain situations such as *professional work* [emphasis added], civic engagement, and personal life.

The above definitions draw attention to three basic elements of the concept of competency.

- It is a latent, acquired, or developed attribute (an ability, capacity, or characteristic) possessed by a person.
- It is related to the intentional execution of tasks.
- It implies a value judgment on the quality of the ability, capacity, or characteristic and that this quality is assessed against formally or informally defined criteria by observing or measuring how effectively intended tasks are performed.

It is important to emphasize that competency and performance are linked. Competencies are internal attributes while performance is the result of these attributes in action. The quality of a competency is assessed by measuring the quality of the relevant performance. There is, however, some ambiguity in the literature about the meaning of *performance* in regard to task or work performance. As Williams (2002, chapters 4 and 5) explains, two positions exist. The first sees performance as output and assesses its quality in terms of deliverables and the bottom line – sales made, units manufactured, defects found, etc. Equivalent measures of performance in an educational environment would be grades achieved. The second position sees performance more in terms of the activity that lies behind output. In this case, the focus is on the behaviors required for such activity to be productive and the quality of performance is assessed in terms of measurable behavioral criteria. For example, one aspect of work performance is the ability and disposition to innovate. Performance as behavior would ask whether a person demonstrates innovative behaviors such as "does not do new things"; "does things to improve performance that are new to the job or work unit, new to the organisation, new to the industry" or are so new they "transform an industry" (Spencer and Spencer 1993, p. 27). In contrast, performance as output would ask how many identifiable innovations have been *delivered*.

Our discussion of the term *competency* emphasizes the mandate of engineering education to develop in students those attributes that a graduate engineer must possess to be capable of (1) producing desired engineering outcomes efficiently, and (2) acting in a manner that is productive and consistent with professional standards. By focusing on the importance of the quality of productive activity, it expands the range of educator attention beyond knowledge and skills to include affective and behavioral issues.

A Generic Classification of the Elements of Competency

Campbell et al. (1993), working in the area of industrial psychology and human resource management, developed a model of the generic determinants of competency that they claimed was comprehensive in scope. The claim is well supported (Williams 2002, p. 99). The Campbell et al. (1993) model is presented as Table 1 with only minor modifications to its language.

The model recognizes three categories of attributes. The first – declarative knowledge – has to do with knowledge that can be communicated. The second has to do with skills and the knowledge intimately associated with skills – procedural knowledge. This kind of knowledge cannot be communicated as it is acquired through practice and the experience of becoming proficient in the associated skill. Subcategories of each kind of knowledge are listed in Table 1

Table 1 The generic elements of competency (Adapted from Campbell et al. 1993, and reproduced here with the kind permission of John Wiley & Sons, Inc.)

Attributes	Subcategories	Factors which influence the quality of the attributes
Declarative knowledge	Facts Principles Goals Self-knowledge	(1) *Aptitudes (and values*[a]*)*: ability, personality, interests (2) *Prior learning experience*: education, training, experience (3) Interactions between aptitudes (values[a]) and prior learning experience
Procedural knowledge and skill	Cognitive skill Psychomotor skill Physical skill Self-management skill Interpersonal skill	(1) *Aptitudes (and values*[a]*)*: ability, personality, interests (2) *Prior learning experience*: education, training, practice, experience (3) Interactions between aptitudes (values[a]) and prior learning experience
Motivation (dispositions[a])	Choices about:- (a) whether to perform (b) the level of effort (c) the degree of persistence	Depends on which motivation theory is used

[a]Added by this author

Knowledge has been classified in other ways but these generally fit with the categories and subcategories used in the model. For example, in her definition of competencies, Passow (2007) refers to the four kinds of knowledge that Anderson et al. (2001) include in their taxonomy of knowledge. These are factual knowledge (terminology and details), conceptual knowledge (classifications, principles, theories, and models), procedural knowledge (knowing how and when to use specific skills and methods), and meta-cognitive knowledge (self-knowledge and both how and when to use cognitive strategies for learning and problem-solving).

The third category in Campbell's model is *motivations*. This has been expanded in the table to include *dispositions*. The reason for this elaboration is that the notion of *dispositions* incorporates a wider range of affective traits, attributes, and commitments along with motivation. It draws attention to how all these factors can influence the way a person actually marshals knowledge and skills and brings them to bear in the performance of his/her work.

Part 2: Perspectives on Engineering Competencies from the Literature

Various perspectives on engineering competency are found in the literature and are discussed in the sections that follow. The progression of the following discussion is similar to that followed in the formulation of the taxonomy. It starts with accreditation standards that describe the competencies that engineering graduates should possess and moves progressively through literature where the focus is more on generic competencies associated with the effective performance of work in general. These are presented in various tables which were primary sources from which the taxonomy was derived. Examples of statements relating to relevant competencies that have emerged since the taxonomy was first formulated in 2002 are also discussed and, in some cases, are also presented in tables.

Perspectives from Accreditation Standards

The literature review behind the taxonomy looked at statements of required learning outcomes found in documents published by national bodies responsible for the accreditation of engineering programs in the USA, South Africa, Australia, Canada, New Zealand, and the UK. Table 2 summarizes and compares the first two of these and shows, not surprisingly, a high degree of consensus. The examination of documentation from the other accrediting bodies mentioned shows a similar

Table 2 Summaries and comparison of engineering education accreditation standards in the United States and South Africa (reproduced here with the kind permission of ABET Inc. and ECSA)

Accreditation Board for Engineering and Technology (ABET Inc.) (2007) (United States)	Engineering Council of South Africa (ECSA) (2004)
Engineering programs must demonstrate that their students attain the following outcomes:	A graduate must be competent to …
(a) Apply knowledge of mathematics, science, and engineering	Apply knowledge of mathematics, basic science, and engineering sciences … to solve engineering problems
(b) Design/conduct experiments and analyze and interpret data	Design and conduct investigations and experiments
(c) Design a system, component or process to meet desired needs within realistic constraints …	Perform creative, *procedural* and *nonprocedural* design and synthesis of components, systems, engineering works, products, or processes
(d) Function on multidisciplinary teams	Work effectively as an individual, in teams and multidisciplinary environments
(e) Identify, formulate, and solve engineering problems	Identify, assess, formulate, and solve *convergent* and *divergent* engineering problems creatively and innovatively
(f) Understanding of professional and ethical responsibility	Demonstrate critical awareness of the need to act professionally and ethically and exercise judgment and take responsibility within own limits of competence
(g) Communicate effectively	Communicate effectively, both orally in writing and, with engineering audiences and the community at large
(h) Broad education necessary to understand the impact of engineering solutions in a global/social context	Demonstrate *critical awareness* of the impact of engineering activity on the social, industrial, and physical environment
(i) Recognition of the need for and the ability to engage in life-long learning	Engage in independent learning through well-developed learning skills
(j) Knowledge of contemporary issues	----
(k) Use the techniques, skills, and tools needed for engineering practice	Use appropriate engineering methods, *skills*, and tools including those based on information technology

degree of consistency. Many of these accreditation standards have been updated since 2002 and the reader is referred to the relevant Web sites for these. (A list of these sites is appended to the references at the end of the chapter.)

The International Engineering Alliance (IEA) published an important article on the desired attributes of engineering graduates (International Engineering Alliance 2005). The IEA is a forum for six international accreditation accords including the Washington, Sydney and Dublin Accords (see http://www.ieagreements.com). These accords are concerned with the globalization of accreditation standards through a process of mutual recognition of the national standards of the signatories to the accords. The article provides a benchmark for the mutual recognition process and the relevant content is presented here as Table 3.

In the UK, work in the EPC (Engineering Professor's Council) produced a statement about outcome standards for engineering programs that was published in an article by Maillardet (2004). The statement resulted from work toward a national accreditation standard. It used the design process as the basis for framing the statement of required graduate competencies. The statement has a somewhat different format and wording than other accreditation standards and so is shown here as a separate table (Table 4).

Table 3 The IEM graduate attributes profile (Extracted from Graduate Attributes and Professional Competencies, International Engineering Alliance 2005, and reproduced here with the kind permission of the IEA Secretariat)

Topic	Graduate attribute
2. Knowledge of engineering sciences	Apply knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the conceptualization of engineering models
3. Problem analysis	Identify, formulate, research literature, and solve complex engineering problems reaching substantiated conclusions using first principles of mathematics and engineering sciences
4. Design/ Development of solutions	Design solutions for complex engineering problems and design systems, components or processes that meet specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations
5. Investigation	Conduct investigations of complex problems including design of experiments, analysis and interpretation of data, and synthesis of information to provide valid conclusions
6. Modern tool usage	Create, select, and apply appropriate techniques, resources, and modern engineering tools, including prediction and modeling, to complex engineering activities, with an understanding of the limitations
7. Individual and team work	Function effectively as an individual, and as a member or leader in diverse teams and in multidisciplinary settings
8. Communication	Communicate effectively on complex engineering activities with the engineering community and with society at large, such as being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions
9. The engineer and society	Demonstrate understanding of the societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to engineering practice
10. Ethics	Understand and commit to professional ethics and responsibilities and norms of engineering practice
11. Environment and sustainability	Understand the impact of engineering solutions in a societal context and demonstrate knowledge of and need for sustainable development
12. Project management and finance	Demonstrate a knowledge and understanding of management and business practices, such as risk and change management, and understand their limitations

(continued)

Table 3 (continued)

Topic	Graduate attribute
13. Life long learning	Recognize the need for, and have the ability to engage in independent and life-long learning

Notes:
(1) Item 1 in the IEM table is not relevant as it refers to a type of educational institution and, therefore, it was omitted from Table 3.
(2) The IEM profiles for technologists and technicians have not been included in this table.
(3) Complex engineering problems and complex activities as used in the IEM Profile are as follows:

Complex Engineering Problems are those which cannot be resolved without in-depth engineering knowledge and having some or all of the following characteristics:

- Involve wide-ranging or conflicting technical, engineering and other issues
- Have no obvious solution and require abstract thinking, originality in analysis to formulate suitable models
- Requires in-depth knowledge that allows a fundamentals-based first principles analytical approach
- Involve infrequently encountered issues
- Are outside problems encompassed by standards and codes of practice for professional engineering
- Involve diverse groups of stakeholders with widely varying needs
- Have significant consequences in a range of contexts
- Are high level problems possibly including many component parts or subproblems

Complex Engineering Activities are those that have some or all of the following characteristics:

- Involve the use of diverse resources (and for this purpose resources include people, money, equipment, materials, information, and technologies)
- Require resolution of significant problems arising from interactions between wide-ranging or conflicting technical, engineering or other issues,
- Involve creative use of knowledge of engineering principles in novel ways.
- Have significant consequences in a range of contexts
- Can extend beyond previous experiences by applying principles-based approaches

Table 4 The EPC outcome standards (Extracted from Maillardet 2004, pp. 33–55, and reproduced here with the kind permissions of Taylor & Francis Books UK)

Primary elements	Elaboration
1. Ability to exercise key skills in the completion of engineering-related tasks	The key skills for engineering are communication, information technology, application of number, working with others, problem-solving, improving own learning, and performance.
	Ability to …
2. Ability to transform existing systems into conceptual models	Elicit and clarify client's true needs
	Identify, classify, and describe engineering systems
	Define real target systems in terms of objective functions, performance specifications, and other constraints (i.e., define the problem).
	Take account of risk assessment, and social and environmental impacts, in the setting of constraints (including legal, health, and safety issues).
	Select, review, and experiment with existing engineering systems to obtain a database of knowledge and understanding that will contribute to the creation of specific real target systems.
	Resolve difficulties created by imperfect and incomplete information.
	Derive conceptual models of real target systems, identifying the key parameters.

(continued)

Table 4 (continued)

Primary elements	Elaboration
3. Ability to transform conceptual models into determinable models	Construct determinable models over a range of complexity to suit a range of conceptual models Use mathematics and computing skills to create determinable models by deriving appropriate constitutive equations and specifying appropriate boundary conditions Use industry standard software tools and platforms to set up determinable models Recognize the value of models of different complexity and limitations of their application
4. Ability to use determinable models to obtain system specifications in terms of parametric values	Use mathematics and computing skills to manipulate and solve determinable models; and use data sheets in an appropriate way to supplement solutions. Use industry standard software platforms and tools to solve determinable models Carry out a parametric sensitivity analysis Critically assess results and, if inadequate or invalid, improve knowledge database by further reference to existing systems, and/or performance or determinable models
5. Ability to select optimum specifications and create physical models	Use objective functions and constraints to identify optimum specifications Plan physical modeling studies based on determinable modeling, to produce critical information Test and collate results feeding these back into determinable models
6. Ability to apply the results from physical models to create real target systems	Write sufficiently detailed specifications of real target systems, including risk assessments and impact statements Select production methods and write method statements Implement production and deliver products fit for purpose, in a timely and efficient manner Operate within relevant legislative frameworks
7. Ability to critically review real target systems and personal performance	Test and evaluate real systems in service against specification and clients needs Recognize and make critical judgments about related environmental, social, ethical, and professional issues Identify professional, technical, and personal development needs and undertake appropriate training and independent research

The CDIO Perspective

CDIO (Conceive, Design, Implement and Operate) is a multinational reform initiative that is concerned to close the gap between engineering education and engineering practice while remaining faithful to both engineering professionalism and the need "to provide quality education in technical fundamentals" (Crawley 2002). The gap between engineering education and practice is explained as the result of a shift that occurred in the middle of the last century in the way that engineering was taught (Crawley

2002; Grimson 2002). The shift was characterized by the increasing prominence given to engineering science in engineering education as compared with the more traditional emphasis on practical engineering (Grimson 2002).

In an effort to close this gap, the CDIO initiative reevaluated the goals of engineering education from the perspective of modern engineering practice and developed a generic syllabus (the CDIO Syllabus) that used design (or, more accurately, CDIO) as its chief organizing principle. As a statement of the goals of engineering education, the CDIO Syllabus became the foundation for the curriculum redesign component of the reform initiative (Crawley 2002; Crawley et al. 2007). It was developed as a collaborative effort between a range of engineering schools (aerospace, mechanical, and electronics engineering) at MIT and three Swedish universities over a 3-year period based on work involving focus groups, surveys, workshops, and peer reviews (Crawley 2002).

The CDIO Syllabus details the many, interrelated processes, knowledge, skills, and attributes involved in engineering a technical system or product from its conception, through design, construction, and implementation, through its operation and eventual life-end and disposal. It also details the external, societal, enterprise, and business contexts in which such engineering is conducted and the personal, interpersonal, and professional skills needed for competent performance of the relevant engineering tasks and processes. The syllabus constitutes the most detailed statement on required graduate competencies currently found in the literature (Woollacott 2007). An abbreviated version and discussion of the CDIO syllabus appear in chapter "CDIO and Quality Assurance: Using the Standards for Continuous Programme Improvement" by Brodeur and Crawley and the full version may be found in Crawley et al. (2007, pp. 257–268) or on the CDIO website (http://www.cdio.org).

Perspectives from Surveys of Engineering Employers and Practicing Engineers

Over the years, many surveys have been conducted to determine which competencies engineering employers look for in engineering graduates (Boeing 1966; Young 1986; Natriello 1989; Busse 1992; Augustine 1994; Kemp 1999; Skakoon and King 2001; de Jager and Nieuwenhuis 2002; World Chemical Engineering Council 2004; Crawley et al. 2007, pp. 58–59). For example, the top five personal qualities/skills employers seek, according to the National Association of Colleges and Employers (2008) *Job Outlook 2009* survey, are:

1. Communication skills (verbal and written)
2. Strong work ethic
3. Teamwork skills (works well with others)
4. Initiative
5. Analytical skills

In his book on studying engineering, Landis (2007, p. 21) lists the top six factors to which US employers refer, in his experience, when considering a graduate engineer for employment. They are as follows:

- Personal qualifications – including maturity, initiative, enthusiasm, poise, appearance, and the ability to work with people.
- Scholastic qualifications – as shown by grades in all subjects or in a major field of study.
- Specialized courses students have taken in particular fields of work.
- Ability to communicate effectively, both orally and in writing.
- Kind and amount of employment while at college.
- Experience in campus activities, especially participation and leadership in extra-curricula life.

A South African study by de Lange (2000) concentrated on eliciting from employers their opinions about the nontechnical attributes they looked for in graduates. *Nontechnical* competencies that de Lange identified as being potentially relevant were grouped into appropriate clusters. Table 5 presents the results of the survey organized by the clusters and the associated competencies that formed the basis of the survey questionnaire used in the study.

An in-depth study of the competencies engineering employers and practicing engineers considered important was conducted recently by Passow (2007). From a comprehensive literature review, she identified 12 studies that had been carried out from 1992 to 2007 (National Society of Professional Engineers 1992; Turley 1992; Evans et al. 1993; American Society of Mechanical Engineers 1995; Benefield et al. 1997; Shea 1997; Koen and Kohli 1998; Lang et al. 1999; Bankel et al. 2003; Saunders-Smith 2005; Lattuca et al. 2006). Of these, ten asked respondents to rate desired graduate competencies on a five-point scale. Passow (2007) reexamined the data in the ten studies using a meta-analysis methodology to obtain a synthesized opinion from the 5,978 respondents to the 19 surveys covered in these ten studies. Passow's (2007) paper also includes 12 tables that summarize the wording used to describe the various competencies included in the 19 surveys.

Passow's (2007) analysis involved mapping the competencies onto the 11 ABET competencies ((a)–(k), see Table 2), transforming the data to a common metric, and using multiple comparison procedures and a careful statistical analysis to distinguish the relative importance assigned by respondents to the different sets of competencies. Relative importance was reported on a five-point scale ranging from +2.5 to –2.5 where 0 represented the *ABET mean* – the average rating for all the competencies that mapped onto the 11 ABET competencies. Competencies that did not map onto the ABET competencies were analyzed separately.

Passow's (2007) findings are summarized in Table 6. Among the ABET competencies, six levels of perceived importance were identified by determining which ratings were statistically different and which were not. As indicated in Table 6, eight competency sets that did not map onto the ABET categories were also shown to fall into or between these six levels of perceived importance. Passow (2007) makes an interesting distinction between competencies and *bodies of knowledge*

Table 5 Nontechnical skills important for engineering graduates (Extracted from de Lange 2000, and reproduced here with the kind permission of G. de Lange)

	Ranked in order of perceived importance	Other skills in questionnaire[a]
Functional skills	The basic skills applied to tasks such as speaking, reading, and writing. They form part of larger actions such as instructing and leading a team of workers.	
(1) Communication	The ability to exchange, transmit, and express knowledge and ideas to achieve set objectives.	
(IR = 1)[b] (RI = 98%)	Verbal communication, listening, explanation, technical report writing, reading, visual and graphic presentation, demonstration	Teaching, grievance handling, conversation, negotiation, conflict management, visual presentation, meeting procedure, interviewing, presentation, selling, persuasion, instruction
(2) Information management	The ability to arrange, sort, retrieve data, knowledge, and ideas.	
(IR = 7) (RI = 84%)	Logical thinking, analysis, prioritizing, reporting, computer application, recording, collection	Retrieval, research, organization, scheduling, synthesizing, sorting, valuation
(3) Creative thinking and problem solving	The ability to solve existing and anticipated problems through creative innovative and analytical means.	
(IR = 2) (RI = 96%)	Problem analysis, observing, questioning, interpreting, investigating, innovating, anticipating, formulating	Forecasting, being creative, interpretation, conceptualisation, prediction, facilitation
Adaptive skills	Skills required to "fit in" and contribute as a valuable member in the work place.	
(4) Personal style and self-management	Indicators of general outlook, personal appearance, values, goals, and motivation.	
(IR = 5) (RI = 87%)	Is motivated, is responsible, is self-confident, is honest, has integrity, is disciplined, is enthusiastic, has positive self-esteem, is adaptable, is determined, is flexible, is conscientious, is ethical, is dependable, is stable	Is assertive, is persistent, is sincere, is patient, is mature, has good appearance, is objective

(5) Work-related dispositions and attitudes	Indicators of personal work orientation, work values, attitudes, and understanding of the work environment.	
(IR = 4) (RI = 91%)	Thoroughness, willing to learn and be trained, committed to job, interest, pride in work, respect for property, understands teamwork, precise, makes extra effort, task orientated, punctual, good work habits, takes initiative, understands work environment, handles pressure and stress	Team member, willing to be trained, accepts criticism, gives credit, open-minded, pride in work, respectful, self-control, takes risks
(6) Group effectiveness and teamwork	The ability to use the correct combination of interpersonal skills to direct and guide a team to complete tasks and attain goals.	
(IR = 3) (RI = 92%)	Cooperates, is responsive, is helpful, coordinates, is compatible, has group process skills, is tactful, is even tempered, is sensitive to cultural diversity, leads and manages, recruits ideas, summarizes	Puts people at ease, negotiates, solicits, has social commitment, is hospitable, is outgoing, supervises, praises, counsels, has empathy, is persuasive
(7) Organizational	The ability to effectively contribute toward the successful completion of a set of organizational goals.	
Effectiveness and teamwork (IR = 5) (RI = 85%)	Meets deadlines, works to schedule, is goal orientated, assumes responsibility, puts theory into practice, works under pressure, prioritizes, makes suggestions, sets objectives, manages time, handles stress, follows procedures, motivates, co-ordinates	Is goal directed, has vision, delegates, leads, directs, administers, manages, supervises, instructs, applies policies, recommends

[a]Details obtained from the author through private correspondence.
[b]Results of the survey are indicated by Importance Ranking (IR) and % Relative Importance (RI).

Table 6 Results of a meta-analysis of the opinions of employers and practicing engineers in regard to desired graduate competencies (Extracted from Passow 2007, and reproduced here with the kind permission of H. J. Passow)

Importance level	ABET criterion	Abbreviation of ABET competency set (importance rating[a])	Non-ABET-based competency sets[b]	
			Skill-related	Attitude-related
1	e	Problem-solving (1.02)		
	g	Communication (0.9)		
1.5			Decision making	Commitment to achieving goals
2	f	Ethics (0.61)		
3	i	Life-long learning (0.39)		
			Able to transition to the industrial environment	Mature, responsible, and open-minded with a positive attitude toward life
			Project management	Personal skills and attributes[c]
			Leadership skills	
4	b	Ability to conduct and evaluate experiments (0.2)		
	d	Team-work skills (0.18)		
	k	Ability to use engineering tools (0.17)		
	c	Design skills (0.06)		
5	a	Maths, science, engineering knowledge (–0.05)		
5.5			Business skills	
6	j	Knowledge of contemporary issues (–1.39)		
	h	Knowledge to assess impact (–1.54)		

[a]The importance rating is a relative indication of importance on a scale from +2.5 to –2.5 where 0 is the ABET mean.
[b]The importance ratings for non-ABET-mapped competencies are not included in the table.
[c]These include initiative and willingness to take risks, perseverance and flexibility, creative and critical thinking, curiosity, life-long learning, time and resource management, and awareness of one's personal knowledge, skills and attitudes

and noted that competencies were uniformly rated by practicing engineers as being more important (levels 1 to 4) than bodies of knowledge (levels 5 and 6) – business skills being the only exception (level 5.5).

Perspectives from Human Resource Management Literature

The perspectives described in the previous section were based directly or indirectly on the results from workplace surveys. A different method for soliciting information from the work place has been used for over 20 years by the McBer Consulting Agency. Their methods and findings have been published in a book entitled *Competency at Work: Models for Superior Performance* (Spencer and Spencer 1993). The work is widely respected (Williams 2002, pp. 102–114).

The motivation for the Agency's work was the need to select personnel and to objectively distinguish between ordinary performers and superior performers. Their approach was to develop a competency model for a particular job by identifying superior performers in that job, interviewing them to discover behavioral traits that characterized their work performance and comparing these findings with those from interviews of "ordinary" performers.

The interviews were conducted by experienced human resource investigators trained in a formalized methodology that had been developed by the Agency over the years. Their task was to identify characteristic behaviors of superior performers and to describe each one in the form of a short narrative description along with measurable behavioral indicators. For example, they identified eight behavioral indicators relating to *self control*. These were: losses control, avoids stress, resists temptations, controls emotions, responds calmly, manages stress effectively, responds constructively, and calms others. Once the set of distinguishing competencies and the related behavioral indicators had been identified, they were arranged into relevant clusters of competencies, which then formed the competency model for the particular job.

Over a span of 20 years, more than 100 trained investigators have developed 286 competency models in over 20 countries. The models cover technical/professional job types as well as jobs in the fields of human service, entrepreneurship, sales/marketing/trading, and managers (in industry, government, military, health care, education, and religious organizations). Technical professionals or *knowledge workers* are defined as "individual contributors whose work involves the use of technical (as opposed to human services) knowledge" (Spencer and Spencer 1993, pp. 161–163). Models for technical professionals have been developed for software developers, engineers, and applied research scientists.

Drawing on this breadth of experience, the Agency extracted generic competencies and behavioral indicators from the models and arranged them into a *competency dictionary*. The dictionary consists of 6 clusters of distinguishing competencies, 21 groups of competencies, and, depending on how you count them, 35 or 28 generic competencies with 360 or 278 behavioral indicators. The dictionary is summarized in Table 7.

Table 7 A summary of the McBer competency dictionary (Extracted from Spencer and Spencer 1993, chapters 4 to 9, and reproduced here with the kind permission of John Wiley & Sons, Inc.)

Distinguishing competency cluster	Competency group	Competency	Number of behavioral indicators
(1) Achievement and action	Achievement orientation	Intensity and completeness of achievement orientation	9
		Achievement impact	7
		Degree of innovation	5
	Concern for order, quality, accuracy	Concern for order, quality, and accuracy	9
	Initiative	Time dimension.	11
		Self-motivation, amount of discretionary effort.	8
	Information seeking	Information seeking	8
(2) Helping and human service	Interpersonal understanding	Depth of understanding of others	7
		Listening and responding to others	7
	Customer service orientation	Focus on client's needs	13
		Initiative (discretionary effort) to help or serve others	7
(3) Impact and influence	Impact and influence	Actions taken to influence others	10
		Breadth of influence, understanding or network	9
	Organizational awareness	Depth of understanding of organization	8
	Relationship building	Closeness of relationships built	9
(4) Managerial	Developing others	Intensity of developmental orientation and completeness of developmental action	11
		Number and rank of people developed or directed	9
	Directiveness: Assertiveness and use of positional power	Intensity of directiveness	11
	Teamwork and cooperation	Intensity of fostering teamwork	9
		Size of team involved	6
		Amount of effort or initiative to foster teamwork	6
	Team leadership	Strength of leadership role	9
(5) Cognitive	Analytical thinking	Complexity of analysis	7
		Size of problem addressed	5
	Conceptual thinking	Complexity and originality of concepts	8
	Technical, professional, managerial expertise	Depth of knowledge	8
		Breadth of managerial experience	7
		Acquisition of expertise	5
		Distribution of expertise	7

(continued)

Table 7 (continued)

Distinguishing competency cluster	Competency group	Competency	Number of behavioral indicators
(6) Personal effectiveness	Self-control	Self-control	8
	Self-confidence	Self-assurance	8
		Dealing with failure	6
	Flexibility	Breadth of change	8
		Speed of change	5
	Organizational commitment	Organizational commitment	8
	Other personal characteristics and competencies	Occupational preference, accurate self-assessment, affiliative interest, writing skills, visioning, upward communications, concrete style of learning and communicating, low fear of rejection, thoroughness	

The generic categories in the dictionary cover from 80 to 98% of the specific categories found in the original competency models. On this basis, the Agency defined a generalized competency model for each of the five different job types mentioned above. It claims that each generalized model describes all jobs of each type in general but none in particular. Their competency model for technical professionals – including engineers – is presented in Table 8. It must be noted that the motivation behind the model is the identification of superior performers and this must be taken into account when using the dictionary. Its scope goes beyond the identification of graduate attributes to be used for accreditation or Quality Assurance purposes: in this regard the model should be taken only as describing *advanced attributes* that are desirable to find in engineering graduates, but are not necessarily expected in all graduates.

Perspectives on Work

An engineer is first of all a worker and so competencies associated with effective work and productive work performance are relevant attributes to be expected in graduate engineers. Landis (2007, p. 84) identified ten different generic settings in which engineers may work (Table 9). The brief descriptions given in that table provide a view on engineering work that complements the other perspectives on engineering competencies described in this review. In the formulation of the taxonomy, two additional types of engineering work were added to Landis' list – maintenance work and entrepreneurial work.

Table 10 presents an augmented version of a taxonomy developed by Campbell et al. (1993) that claims to encompass the major performance components required in any kind of job. Williams (2002), in his review of the related literature, suggests

Table 8 Summary of McBer's generalized competency model for technical professionals (Extracted from Spencer and Spencer 1993, p. 163, and reproduced here with the kind permission of John Wiley & Sons, Inc.)

Competency	Relative weight[a]	Behavioral indicators
(1) Achievement orientation	6	Measures performance Improves outcomes Sets challenging goals Innovates
(2) Impact and influence	5	Uses direct persuasion, facts, and figures Gives presentations tailored to audience Shows concern with professional reputation
(3) Conceptual thinking	4	Recognizes key actions, underlying problems Makes connections and patterns
(4) Analytical thinking	4	Anticipates obstacles Breaks problem apart systematically Makes logical conclusions Sees consequences, implications
(5) Initiative	4	Persists in problem solving Addresses problems before asked to
(6) Self-Confidence	3	Expresses confidence in own judgment Seeks challenges and independence
(7) Interpersonal understanding	3	Understands attitudes, interests, needs of others
(8) Concern for order	2	Seeks clarity of roles and information Checks quality of work and information Keeps records
(9) Information seeking	2	Contacts many different sources Reads journals etc.
(10) Teamwork and cooperation	2	Brainstorms, solicits input Credits others
(11) Expertise	2	Expands and uses technical knowledge Enjoys technical work, shares expertise
(12) Customer service orientation	1	Discovers and meets underlying needs

[a]The relative weight is the frequency with which the competency appeared in the specific competency models from which the generalized model was derived.

Table 9 Descriptions of engineering work (Adapted from Landis 2007, pp. 84–87)

Job function	Description
1. Analysis	Does mathematical modeling of the physical and/or chemical aspects of problems using physics, chemical and engineering sciences, numerical and mathematical procedures, and engineering software.
2. Design	Converts concepts and information into detailed plans and specifications for the development, manufacture or building of a product, component, system or process.
3. Testing	Develops and conducts tests to verify that a selected design or product meets all specifications.
4. Development	Develops products, processes or systems. Somewhere between the design and testing job functions.
5. Selling	A technical liaison person between the company and the customer. Must be technically proficient to understand both the product and the customer's needs.
6. Research	Involved in the search for new knowledge. Differs from a research scientist in that the motivation for the new knowledge is not knowledge for its own sake but knowledge that can be applied for the advancement of engineering practice.

(continued)

Table 9 (continued)

Job function	Description
7. Line management	Involved as technical staff in the supervision of designated aspects of the "production line" in engineering production enterprises. The involvement may be at various points in the supervision hierarchy from junior engineer to chief engineer to company president.
8. Project management	Differs from line management in that personnel are organized according to a specific project and are responsible to ensure that the project is completed successfully, on time and within budget.
9. Consulting	Provides "expert" technical services for a client on a contractual basis.
10. Teaching	Works in an academic environment and is involved with teaching, research, and providing services in a specific area of an engineering discipline.

Table 10 A taxonomy of major performance components (Extracted from Campbell et al 1993, except for item 9, and reproduced here with the kind permission of John Wiley & Sons, Inc.)

Performance component	Description
1. Job-specific task proficiency	Proficiency in performing the core substantive or technical tasks that are central to the job. Job-specific performance behaviors that distinguish the substantive content of one job from another.
2. Non-job-specific task proficiency	Proficiency in performing tasks or executing performance behaviors which are not specific to one's particular job – e.g., an engineer doing administration or sitting on the safety committee.
3. Proficiency in written or oral communication	Proficiency in writing or speaking (independent of the correctness of the subject matter).
4. Demonstrating effort	Consistent commitment to all job tasks, to working at a high level of intensity and the willingness to keep working under adverse circumstances and to expend extra effort when required.
5. Maintaining personal discipline	The degree to which negative behaviors – such as alcohol abuse and absenteeism – are avoided.
6. Facilitating peer and team performance	Supporting and helping peers and facilitating group functioning by being a good model, keeping the group goal directed, and reinforcing participation by other group members.
7. Supervision and leadership	Influencing the performance of subordinates through interpersonal interaction and influence, modeling, goal setting, coaching, and providing reinforcement. Similar to (6) but supervisory leadership involves different performance determinants than peer leadership.
8. Management and administration	Involves processes additional to those in (7) such as articulating goals for a production unit or enterprise, organizing people or resources to achieve these, monitoring progress, helping to solve problems or overcome crises that stand in the way of goal accomplishment, controlling expenditures, obtaining additional resources, and representing the unit in dealing with other units.
9. Adaptive performance	"Ease of learning new tasks, confidence in approaching new tasks, flexibility and capacity to cope with change,"[a] "capacity to engage with new learning in coping with change,"[b] "developing oneself."[c]

[a] (Hesketh and Neal 1999)
[b] (London and Mone 1999)
[c] (Williams 2002, p. 96)

that the taxonomy overlooks performances that have to do with self-development and adaptation to the fast pace of change characteristic of modern work environments (see also Hesketh and Neal 1999, and London and Mone 1999). Williams also noted terminology in the literature that differed from Campbell's as well as differences in emphasis and some differences in approach. On reflection, however, he concluded that (1) the differences were not very significant, (2) that Campbell's categories augmented with *adaptive performance* were an adequate general description of the major components of work performance, and (3) that the augmented taxonomy provides a reliable framework for making sure that no aspect of work performance is overlooked when analyzing the nature of any particular job.

Table 11 presents a perspective developed during the formulation of the taxonomy as a basic framework for describing the different aspects of an individual's work (Woollacott 2003). The rationale here is that different types of work functions require different profiles of competencies. For example, the competency mix needed for initiating work is different from the one needed for acquiring resources. The work functions in the taxonomy in the table are generic, however, in that each type of work function is associated with a similar competency profile in any context. For example, the initiation of a new project, a new task, a new procedure, or a new organization all involve similar kinds of functions although the extent and complexity of the competencies involved will be very different.

The perspective in Table 11 was formulated with inexperienced students in mind – students with limited experience or perception of what skills and attitudes are needed for satisfactory execution of tasks. The idea was to spell out to them what was involved and what they needed to give their attention to in order to develop the ability to execute work-related tasks in an ongoing and sustained way. It was considered to be particularly important for them to appreciate that besides the *core work functions* that get the job done, *support work functions* are very important to support, monitor, guide, and enable the efficient execution of core work functions.

The purpose of the taxonomy in Table 11 is to distinguish clearly what the two kinds of work functions involve. The first nine of these are self explanatory and are identified in various forms in other perspectives found in the literature. The tenth work function, *house keeping*, emphasizes the need to pay attention to resources – both one's own as well as those made available in the work environment. This work function is at the root of important factors such as tidiness, order, organizing resources effectively and caring properly for equipment, finances, and the capacity to sustain good work. This aspect of competency is considered to be of particular relevance to inexperienced learners, some of whom have little or no real awareness of the importance of these issues.

Table 12 presents the taxonomy of World of Work Skills developed by Evers et al. (1998). This taxonomy resulted from a project in Canada called *Make the Match* which was concerned with skills and human resource development, the relationship of education to work, and how to modify curricula to better prepare graduates for the world of work. The project was spear-headed by a nine-person task force (five corporate CEOs and four university presidents). Interestingly, it began with the intention of focusing on technical skills, but during the process of

Table 11 A taxonomy of individual work functions (Woollacott 2003)

Category	Work function
Line or core work functions	(1) *Initiating work*: This involves reflecting on and examining the technological, business, and social environments in which the organization operates. The purpose is to identify possible areas for expanding existing activities or markets and opportunities for new products, technology or services. (2) *Planning work*: The nature and requirements of the work must be properly analyzed and understood. The work to be done must be broken down into subtasks that are appropriate, manageable, well defined, and properly prioritized and scheduled. (3) *Acquiring resources for the work*: The staff, physical resources, information, and skills needed to accomplish the work must be acquired from the general market place or from within the organization, or from colleagues, consultants, suppliers or information systems. In some cases, this will involve learning by personal study or engaging in research and development. (4) *Performing subtasks*: The worker must bring his/her knowledge and the acquired resources to bear effectively to accomplish each of the required subtasks. (5) *Evaluating and synthesizing results*: The results from the different tasks must be brought together, properly evaluated and synthesized appropriately to achieve the overall objectives.
Support work functions	(6) *Managing the work*: This involves ensuring that the various aspects of work – both core and support work functions – are properly coordinated, are progressing in a satisfactory manner, and that problems that occur are dealt with appropriately. (7) *Evaluating effectiveness (productivity, profitability, quality, service and impact)*: This involves giving attention to the quality and effectiveness of the work effort and its results, and being sensitive to the impact the work makes or could make on the organization, the market, society, and the environment. This involves the examination of and the exercise of judgment about a broad range of factors from technical, financial, social, and legal, to the evaluation of alternative solutions, implementability, and issues of health and safety. (8) *Interacting with people*: The worker must be competent not only to work alone, but also as a member or leader of a team. Good teamwork involves making effective personal contributions, interacting with team members in ways that enhance their contributions, facilitating the productivity of the team and dealing effectively with interactional problems. In addition, a person may need to interact professionally with clients or with members of the public as a representative of the organization. (9) *Communication*: An important aspect of interacting with people is the ability to communicate effectively verbally, graphically and in writing with colleagues, clients, superiors, and subordinates. (10) "*Housekeeping*": This involves ensuring that the resources and capacity to do good work are maintained, sustained and, where necessary, are developed further.

Table 12 The taxonomy of world of work skills (Extracted from Evers et al. 1998, p. 40, and reproduced here with the kind permission of John Wiley & Sons, Inc.)

Managing self		
Constantly developing practices and internalizing routines for maximizing one's ability to deal with the uncertainty of an ever-changing environment	Learning	Gaining knowledge from everyday experiences
		Keeping up to date on developments in the field
	Personal organization and time management	Managing several tasks at once
		Setting priorities
		Allocating time efficiently to meet deadlines
	Personal strengths	Developing personal traits for dealing with day-to-day work situations. (For example, maintaining a high energy level, motivating oneself to function at an optimal level of performance, functioning in stressful situations, maintaining a positive attitude, being able to work independently, and responding appropriately to constructive criticism.)
	Problem-solving and analytical	Identifying, prioritizing, and solving problems, individually or in groups. It involves the ability to ask the right questions, sort out the many facets of a problem, and contribute ideas as well as answers regarding the problem.
Communicating		
Interacting effectively with individuals and groups to facilitate the gathering, integrating, and conveying of information in many forms (example, verbal, written)	Interpersonal	Working well with others (superiors, subordinates, and peers), understanding their needs, and being sympathetic to them.
	Listening	Being attentive when others are speaking
		Responding effectively to others comments during a conversation
	Oral communication	Effectively presenting information to others, either one-to-one or in groups
	Written communication	Effectively transferring information, either formally (through reports and business correspondence for example) or informally (through notes or memos).

Managing people and tasks		
Accomplishing the tasks at hand by planning, organizing, coordinating, and controlling both resources and people	Coordinating	Coordinating the work of peers and subordinates
		Encouraging positive group relations
	Decision-making	Making timely decisions based on thorough assessments of the short- and long-term effects of decisions
		Recognizing political and ethical implications of decisions
		Identifying stakeholders and those who will be affected by the decisions made
	Leadership and influence	Directing and guiding others
		Delegating work tasks to peers and subordinates in an effective manner
		Motivating others to do their best
	Managing conflict	Identifying sources of conflict between oneself and others, and between other people
		Taking steps to overcome disharmony
	Planning and organizing	Determining required tasks to meet objectives (strategic and tactical)
		Assigning tasks to others appropriately
		Monitoring progress made against the plan
		Revising plans as necessary to include new information
Mobilizing innovation and change		
Conceptualizing, as well as setting in motion, ways of initiating and managing change that involves significant departures from the current mode	Ability to conceptualize	Combining relevant information from a number of sources
		Integrating information into more general frameworks
		Applying information to new or broader contexts
	Creativity, innovation, change	Adapting to situations of change
		Initiating change
		Providing novel solutions to problems
		Re-conceptualize roles in response to changing demands related to success
	Risk-taking – (taking reasonable job-related risks)	Recognizing alternative or different ways of meeting objectives
		Recognizing potential negative outcomes
		Monitoring progress toward the set objectives
	Visioning	Conceptualizing the future of the company
		Providing innovative paths for the company to follow

open-ended interviews and a survey it became clear that graduates and managers were much more concerned about the quality of generic skills such as written communication. Accordingly, the taxonomy in Table 12 was developed "to provide practitioners of higher education and workplace training with a common language of general skills needed by college and university graduates for life long learning and employability" (Evers et al. 1998, p. xviii). It concentrated on "generalist skills that higher education graduates need as a base supporting their specialist knowledge and skills" (Evers et al. 1998, p. xix).

Research Perspective: How Generic Graduate Attributes Are Understood

This literature review began by looking at the full range of competencies desired in an engineering graduate. Its attention then moved increasingly toward the competencies needed for effective performance of work in general. The review will conclude by looking at an interesting Australian paper by Barrie (2006) which steps back from the concern to produce a list of graduate attributes and looks rather at what is understood by the term *generic graduate attributes* (GGA) – the so-called *soft skills*, *nontechnical competencies*, or *critical-cross-field outcomes*. This shift in focus is illuminating not only because the way generic attributes are understood affects how they are addressed in curricula, but also because it draws attention to the underlying nature of GGA and how they interrelate with the hard attributes of engineering knowledge and engineering application skills.

The paper by Barrie (2006) describes the findings of a phenomenographic study that was intended to identify the qualitatively different ways in which academics perceived the term *generic graduate attributes*. Four categories of perception were identified as follows:

1. GGA are *precursor skills* – "necessary basic … skills but irrelevant [to teaching in higher education] as they are a prerequisite for university entry" (p. 225). From this perspective, only disciplinary knowledge and skills should be included in the curriculum – they constitute the foreground – while GGA and other learning outcomes function merely as a *backdrop* and receive little formal attention in the tertiary classroom.
2. They are *complementary skills* – "useful skills that complement or round out disciplinary learning" (p. 226). In this perspective, GGA have a place in the curriculum but only as stand-alone modules that are not explicitly linked to disciplinary knowledge or skills.
3. They are *translation skills* – "abilities that let students translate, make, use, or apply disciplinary knowledge to the world" (p. 227). This acknowledges the role of GGA in the application of disciplinary knowledge and skills. Accordingly, their inclusion in the curriculum should, where appropriate, be explicitly linked to disciplinary knowledge.

4. They are *enabling skills* – "abilities that infuse and enable university learning and knowledge" (p. 229). Here the relation between GGA and disciplinary skills and knowledge is recognized to be more intimate to the extent that a graduate's level of competency is determined by the degree to which disciplinary skills and knowledge are interwoven and empowered by GGA.

These categories are of interest to this review in the following ways:

- They emphasize and clarify a number of points noted elsewhere in the review, especially in regard to the relative importance of competencies, bodies of knowledge, and technical and nontechnical knowledge and skills. As will be seen, they confirm perceptions that were important to but not clearly articulated in the development of the taxonomy.
- Barrie (2006) indicates that the progression from precursor to complimentary to translational to enabling skills suggests increasing recognition of the importance of generic attributes to the effectiveness of productive activity. In defining generic attributes as *precursor* or *complementary* the perception is that generic attributes are *discrete from* disciplinary knowledge. Defining them as *translational* and *enabling* means that they are perceived as *transformative of* disciplinary knowledge. For example, when generic attributes are defined as *translational* skills they are seen as *essential partners* of disciplinary knowledge in productive activity. When they are perceived as *enabling* skills, they are seen as the *primary and essential substrate* of productive activity that deploys and marshals disciplinary knowledge and skills in effective and appropriate ways.
- Interestingly, the perception of generic attributes as *precursor* skills makes the important point that the generic attributes that students bring with them to university are important and influential. As will be seen, this observation is a significant element in the motivation behind the development of the taxonomy.

Part 3: The Taxonomy of Engineering Competencies

The taxonomy of engineering competencies was developed between 2001 and 2002 in the School of Chemical and Metallurgical Engineering at the University of the Witwatersrand, Johannesburg, South Africa (Woollacott 2003). It was formulated as part of a curriculum reform initiative set in the context of the major societal change emanating from the demise of apartheid and the considerable shift in the demographics and educational backgrounds of students entering higher education that was brought about by that change.

All the challenges associated with the massification of higher education experienced elsewhere in the world (Tinto 1975; Knight et al. 2003; Lomas 2004) are particularly acute in the South African educational landscape. In the references cited, the so-called *traditional student*[2] typically constitutes the minority of the student intake: in South Africa they constitute the majority (Woollacott et al. 2003). Levels of *under-preparedness* are high among incoming students as a result of socio-economic factors (Phurutse 2005) and the aftermath of apartheid education that had fostered an inferior education system for the majority of the population (Simpkins 2005). In addition, rates of attrition and academic failure were high and remain high (Pinto 2001; Letseka and Maile 2008).

As can be appreciated, the circumstances just described present significant challenges to any educational restructuring effort. The purpose of the taxonomy was to articulate needed graduate competencies in a way that was appropriate to the restructuring of the first-year program, particularly in regard to the introductory engineering course. How the taxonomy was developed and the rational behind its formulation is the subject of this part of the chapter.

The Issue of Responsiveness

In Part 1, the four primary stakeholders in engineering education were identified based on the theory of curriculum responsiveness. To satisfy the requirement to be appropriately responsive to the interests of economic and disciplinary stakeholders, the taxonomy needed to embody the learning outcomes articulated in the national accreditation standards formulated by ECSA – the Engineering Council of South Africa (ECSA). (A shortened version of these has already been presented in Table 2.)

Given the context of a society deeply committed to the transformation of its citizenry, societal responsiveness was a particularly important issue. To satisfy the requirements to be appropriately responsive to societal needs, the *taxonomy* had to articulate competencies that had to do with personal transformation in terms of the issues articulated in ECSA standards and the issues raised in the section on responsiveness in Part 1.

Many of these issues have to do with the GGA addressed in the ECSA standards. However, these attributes articulate the end point of the educational process and give no attention to the diversity of student attributes at the start of that process. In addition, they do not stress sufficiently the competencies associated with "participating as responsible citizens" or of being an agent of social upliftment by virtue of being a competent graduate. The primary way the taxonomy addressed these concerns was to place particular emphasis on the engineer as a worker and as a leader.

[2]Ellsworth (1989, p. 297) in the context of higher education in the USA, refers to the mythical *traditional students* as "young, white, heterosexual, Christian, able-bodied, thin, middle-class, English-speaking, and male." To this description should be added the advantage of having received a good secondary education.

To satisfy the requirement of being appropriately responsive to learners, the taxonomy had to articulate graduate competencies in a way that took into account the diversity of the competencies of incoming students and how these needed to be developed in relation to required graduate attributes. To understand how the taxonomy addressed this concern, it is necessary to discuss the issue of learner responsiveness in the context of under-prepared students.

Quality and Responsiveness to the Learner When Under-Preparedness Is an Issue

Engineering education facilitates a developmental journey that learners take to prepare themselves for a professional career. Each engineering program is designed according to assumptions about the competencies of the entrants to the program. There are formal expectations and informal ones. The formal assumptions are based on the specified outcomes of the relevant secondary education. The expectation is that the associated assessment procedures have been effective so that students who obtain the required qualifications actually posses the expected competencies. Informal expectations have to do with assumptions about proficiency in the language of instruction, study and life skills, and competencies "picked up" during secondary education, but not formally assessed. Examples of the latter include a good work ethic, reasonable questioning skills, and an inclination to learn by seeking understanding rather than by memorization.

Massification of education is usually accompanied by a diversification of the attributes of incoming students (Lomas 2004). Consequently, a mismatch frequently arises between the competencies of some of the incoming students and the assumed competencies on which existing educational programs are based. In a sense, the programs are under-prepared for the students (Masenya 1995). From the reverse point of view, incoming students may be under-prepared for the programs they enter in that their competencies are different to or compare negatively with the assumed competencies on which the curriculum is based (Masenya 1995; Woollacott et al. 2003).

At least some of the student attrition and academic failure among first year students can be shown to result from this mismatch rather than to other factors. This is demonstrated by the relative success of some of the educational interventions that have managed to improve the academic performance of under-prepared students (Hillman 1992; Pinto 2001; Knight et al. 2003).

A quality educational program will be appropriately responsive to the needs of its students. When under-preparedness is an issue, it suggests a need to restructure the program in such a way that it is better able to accommodate the diversity of the entering students. Such restructuring clearly should be based on a reevaluation of the academic, personal, and professional developmental journey the students must follow to achieve the desired learning outcomes and become competent engineering graduates.

Some of the elements of the developmental journey which under-prepared students must follow are easily identified and some are not. In some cases, *gaps* clearly exist in the knowledge and skills base of some students – for example, their proficiency in discipline knowledge and skills is inadequate (Rollnick et al. 1998; Taylor and Chou 1999; Malcolm and Zukas 2001; Mumba et al. 2002). In other cases, there is a lack of proficiency in the language of instruction (Miller et al. 1997; von Gruenewaldt 1999) and life-of-the-mind that is the focus of higher education. Restructuring here involves the provision of extra modules or support systems to address the gaps. This approach has been the primary tactic used in South Africa from 1980 onwards (Pinto 2001; Woollacott 2003; Woollacott 2006).

Many aspects of under-preparedness among students, however, are more subtle and are not manifested only in simple ways such as obvious gaps in knowledge and skills. In South Africa, for example, the learning practices of many incoming students have been deeply shaped by education approaches that emphasize and develop surface approaches to learning (Hillman 1992; Grayson 1996; Simelane 2006) – an emphasis on memorization, reliance on proficiency in "doing past papers," and the development of skill in recognizing patterns in exam questions and applying standardized solution methods (Simelane 2006). Students are strongly shaped by their past experiences. Years of immersion in schooling that promotes the development of such inappropriate learning practices leave a deep imprint that strongly affects how students view and engage with the world of tertiary learning. Such influences, combined with the impact of socio-economic disadvantage and, in extreme cases, limited exposure to the world of technology, result in student under-preparedness, the nature and impact of which is not easy to understand or to address effectively in educational restructuring.

How can a curriculum be appropriately responsive to learners who display the subtle features of under-preparedness just described? The primary motivation behind the development of the taxonomy was to address this question. The thinking that was involved will be explained in terms of GGA.

Development of the Taxonomy

The motivation for developing the taxonomy was therefore to provide a better handle on what attributes needed to be developed, how they related to disciplinary knowledge and skills, what they might look like in embryonic form in incoming students, and how to be alert to inappropriate attributes. So as not to lose sight of the larger objectives of economic, disciplinary, and societal responsiveness, the taxonomy was developed as a statement pertaining to the full range of generic engineering competencies.

The strategy that seemed to offer the most effective way to achieve the objectives just outlined was to focus on the engineer as a worker – to focus on engineering work and the competencies and dispositions needed to do it well. In essence, the taxonomy was seen as a detailed answer to the broad question of what is involved in working as a competent engineer.

As noted above, the taxonomy was derived from a broad ranging literature review that included but looked beyond the sources that are normally accessed for the genesis of statements on graduate attributes. What is particularly significant about the t*axonomy* (Table 13) is that its organizing rationale is based on respected theory and its content is derived from both respected theory and strong research evidence.

In this regard, the following features of the taxonomy give weight to the claim that it is comprehensive in its coverage of the issues it addresses.

- The organization of its first level detail is based directly on a well-respected model of generic work (Campbell et al. 1993). That model claims to comprehensively describe the components of any type of job – a claim that has significant support in the field of industrial psychology and human resource management (Williams 2002, pp. 97–99). The nine items in the augmented Campbell model (Table 10) have been collapsed into five categories in the taxonomy. Organizing the taxonomy around these categories therefore provides a theory-supported claim that no aspect of work, at least at a generic level, has been overlooked.
- The content of the taxonomy is organized to give appropriate attention to three dimensions of competency – knowledge, skills, and dispositions. As indicated earlier, these correspond to the categories found in another Campbell model (Table 1) that claims to comprehensively describe the generic determinants of competency (Campbell et al. 1993).
- In the language of Barrie (2006), GGA are conceived primarily as enabling skills that are deeply embedded and interwoven with other attributes. Because the taxonomy is a classification of competencies, it makes distinctions that, to some extent, hide the interdependence between knowledge, skills, and dispositions.
- The descriptions of the knowledge and skills expected in a competent engineer are derived from the literature on accreditation standards and descriptions of engineering work as well as from published findings of surveys of stakeholder opinion.
- In the taxonomy, *dispositions* are used as a composite term that includes attitudes, traits, values, interests, orientations, commitments, and motivations. As the discussion about the generic elements of competency (Table 1) shows, it is a person's dispositions that determine the way in which that person's knowledge and skills are actually marshaled and brought to bear in the performance of his/her work.
- The seventh category in the taxonomy – advanced dispositions – was extracted from a competency model for technical professionals (Spencer and Spencer 1993, p. 163). As described earlier, the research on which the models were based was carefully structured to identify the characteristic behaviors that distinguished superior from ordinary performers. The reliability and comprehensiveness of these insights rests on the extensive range of the data collected and on the degree of rigor with which the data were analyzed and the research was conducted.

Table 13 A taxonomy of engineering competencies (Woollacott 2003)

1st level categories	2nd level categories	(3rd level categories and 4th level detail) Ability, disposition or understanding
(A) Engineering – specific work	General engineering work	(1) Perform the different aspects of any engineering work or task namely initiating and planning the work/task, acquiring the resources needed, performing subtasks and evaluating and synthesizing results.
		(2) Use appropriate engineering and computer methods, skills and tools and properly assess, analyze, and interpret the results they yield.
		(3) Evaluate effectiveness, productivity, profitability, quality, service, impact or implications of any aspect of work done or planned and a disposition to do so.
		(4) Arrange, sort, retrieve and properly assess data, knowledge, and ideas.
	Specialist engineering work	(5) Perform *analytical work* to solve existing and anticipated engineering problems and model relevant systems by (a) applying knowledge of mathematics and the natural, engineering and computational sciences, and (b) identifying, assessing, formulating, and solving convergent and divergent engineering problems in a creative and innovative way.
		(6) Perform *design work* by converting concepts and information into detailed plans and specifications for the development, manufacture or operation of systems, processes, products or components that meet desired needs.
		(7) Plan and perform *investigations* to (a) *test* that a design or product meets specifications, (b) *develop* products, components, systems or processes, or (c) *search for new knowledge* that can be applied for the advancement of engineering practice.
	Engineering mixed with other work	(8) Integrate specialist engineering work appropriately with work relating to core functions of an enterprise, management, administration, supervision, projects, sales, consulting, entrepreneurship or teaching in order to achieve the broader aims of the business enterprise or stated objectives in the different generic settings of engineering work. These are analysis, design, testing, development, maintenance, selling, research, line management, project management, consulting, teaching, and entrepreneurial endeavor.
(B) Non-engineering-specific work	General	(9) Perform tasks and execute behaviors not specific to one's particular job.
		(10) Manage one's personal work effectively to ensure that all aspects are properly coordinated, are progressing in a satisfactory manner and that problems that arise are identified and are dealt with appropriately.
		(11) Support and help peers and facilitate group functioning by being a good model, keeping the group directed and reinforcing participation by other group members.
		(12) Ensure that the resources and capacity to do good work are maintained, sustained, and, where necessary, developed further.

	Supervision, leadership	(13) Influence the performance of subordinates through interpersonal interaction and influence, modeling, goal-setting, coaching, and providing reinforcement.
		(14) Function as a supervisor in the "line production" activities of the enterprise at the appropriate designated position in the supervision hierarchy.
	Management, administration	(15) Articulate goals for a unit/enterprise, organize people and resources to achieve these, monitor progress, help solve problems or overcome crises that stand in the way, control expenditures, represent the unit in dealing with other units or clients.
		(16) Manage a project and ensure that it is completed successfully, on time and within budget.
(C) Communication		(17) Effectively exchange, transmit, and express – verbally, graphically and in writing – knowledge and ideas to achieve set objectives when communicating with colleagues, peers, clients, superiors, subordinates, engineering audiences, or the larger community.
(D) Interpersonal interactions	Personal	(18) Interact effectively and positively with colleagues, clients, superiors, subordinates, engineering audiences and the larger community.
	Teamwork	(19) Function effectively on multidisciplinary teams through personal contributions and interactions with others that enhance their contributions.
(E) Dispositions		Ability, disposition or understanding
(E1) Personal dispositions	General	(20) Agreeable personal style, characteristics, and self-management including maturity, initiative, enthusiasm, poise, appearance, values, goals, outlook, and motivation.
		(21) Disposed to consistent commitment to all job tasks, to working at a high level of intensity and the willingness to keep working under adverse circumstances and to expend extra effort when required.
		(22) Disposed to taking responsibility within own limits of competence.
		(23) Interest and knowledge in contemporary issues.
	Discipline	(24) Disposed to maintaining personal disciplines and avoiding negative behaviors.
		(25) Being critically aware of the need to act professionally and ethically.
		(26) Being critically aware of the impact of engineering activity in a global/social setting.
(E2) Adaptive dispositions	Self- development	(27) Disposed to improving personal competencies in general.
		(28) Understands nature/importance of effective learning skills and is able to apply them.
		(29) Able to assess one's own performance effectively and accurately.
		(30) Disposed to improving critical knowledge, skills, and dispositions in an effort to sustain or improve one's reputation and advancement prospects.

(continued)

Table 13 (continued)

1st level categories	2nd level categories	(3rd level categories and 4th level detail) Ability, disposition or understanding
	Life-long learning	(31) Understands the requirement to maintain continued competence.
		(32) Able to and disposed to engage in independent and interdependent life-long learning through well developed learning skills.
	Change management	(33) Able to manage the impact of change effectively and flexibly, and to engage in new learning in coping with change.
(E3) Advanced dispositions	Achievement orientation	(34) Works to meet required standards but also creates own measures of excellence.
Extracted from the competency dictionary and generalized competency model for “technical professionals” (Spencer and Spencer 1993, p. 163)		(35) Disposed to improve performance or improve morale, revenues or customer satisfaction by making specific changes in the system or in own work methods.
		(36) Sets and acts to reach challenging goals for self and others.[a]
		(37) Innovates.
	Impact and influence	(38) Gives presentations tailored to audience, calculates the impact of own actions/words and adapts presentations or discussion to appeal to the interest and level of others.
		(39) Shows concern with professional reputation.
	Conceptual thinking	(40) Recognizes key actions and underlying problems by observing discrepancies, trends and interrelationships, crucial differences, past discrepancies.
		(41) Able to condense large amounts of information in a useful manner.
		(42) Makes connections and patterns by pulling together ideas, issues, and observations into a single concept and identifies key issues in complex situations.
	Analytical thinking	(43) Anticipates obstacles, breaks problem apart systematically, makes logical conclusions, sees consequences and implications.
	Initiative	(44) Persists in problem solving when things do not go smoothly. Exceeds job description. Addresses problems before asked to. Creates opportunities.
	Self-confidence	(45) Expresses confidence in own judgment. Sees self as a causal agent, prime mover.
		(46) Seeks challenges and independence, welcomes challenging assignments, seeks additional responsibility, states own position clearly and confidently.
	Interpersonal understanding	(47) Understands attitudes, interests, needs of others and is good at discerning the unspoken thoughts, concerns or feelings of others.

Concern for order	(48) Seeks clarity of roles and information, checks quality of work/information, keeps records and an organized workplace, monitors data, projects, and the work of others.
Information seeking	(49) Asks questions, personally investigates, digs deeper, calls or contacts others, does research, uses own ongoing systems, involves others.
Teamwork and cooperation	(50) Genuinely values others' input and expertise and is willing to learn from others.
	(51) Empowers others, encourages those who perform well and gives them credit.
Expertise	(52) Applies technical knowledge to achieve additional impact, goes beyond simply answering a question and helps resolve others' technical problems.
	(53) Exhibits active curiosity to discover new things, makes major efforts to acquire new skills and knowledge, and to maintain an extensive network of relevant contacts.
Service orientation	(54) Seeks information about the real, underlying needs of the client, beyond those expressed initially, and matches these to available (or customized) products or services.

[a]"'Challenging' means there is a 50–50 chance of actually achieving the goal – it is a definite stretch, but not unrealistic or impossible" (Spencer and Spencer 1993, p. 26)

Conclusions

The description of the development of the taxonomy has been presented as a case study that shows how a statement of graduate attributes has been formulated for a specific educational context. It has shown how that formulation has applied the principles of curriculum responsiveness as a basis for identifying the stakeholders of engineering education and how this basis has been pursued in the attempt to address the concerns of each stakeholder. It has shown that theory can be exploited to enhance the credibility of a statement about desired graduate attributes. It draws attention to the interrelatedness of the attributes that make up competency and make for productive activity.

Engineering practice is not static. Not only is new technology being developed all the time, but also there are shifts in emphasis, in the kinds of demands placed on engineers and, therefore, in how graduate engineers need to be educated. Consequently, the need from time to time to modify an existing curriculum or to develop a new one should be recognized to be a permanent feature of engineering education. Statements of the goals of engineering education which usually inform such educational restructuring should likewise be subjected to periodic review and updating. I trust that this case study and the literature review it embodies may serve as a useful resource for any involved in the future design, redesign, or delivery of engineering education programs.

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