Dealing with Under-Preparedness in Engineering Education
Part 1: Defining the Goal:
A Taxonomy of Engineering Competency

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ABSTRACT

This paper emerges from work conducted on the problem of effectively addressing under-preparedness in entrants to university engineering programs in South Africa. Any educational curriculum is based on a conception of the developmental journey a learner must take in becoming a competent graduate. The conceptions underlying traditional engineering curricula do not match well with the journeys that under-prepared students with ability should take to reach their potential fully. To work towards a better match between conception and reality requires deeper understanding of the nature of under-preparedness, of engineering competency and of the determinants of engineering competency (that is, the underlying factors that determine the quality of the competencies). The first of these areas will inform the process of curriculum design by clarifying the starting point of the developmental journey. The second area will clarify the goal and the third will help to clarify what must be done to get there. This paper addresses the second of these issues – understanding engineering competency.

Eight different perspectives on engineering competency have been extracted from the literature and a ninth is developed in the paper. Analysis of their similarities and differences provides a basis for developing a broader, integrated perspective that is presented as a taxonomy of engineering competency. How the taxonomy is used in acquiring a deeper understanding of competency determinants and under-preparedness will be explored in two follow up papers.

1. Introduction

Engineering education facilitates a developmental journey that learners take in order 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 the competencies 'picked up' during secondary education but not formally assessed. In addition, certain culturally based and linguistically based perceptions and competencies are assumed.

Under-preparedness is the condition where the competencies of the learner compare negatively with the assumed competencies on which the curriculum is based. Also significant is the existence of a mix of deficiencies and alternative conceptions that have problematic consequences for the learners as they progress through the program. The primary causes of under-preparedness are deficiencies in the student's educational history. In South Africa, such causes are exacerbated by historical disadvantage, 'educational backlogs' and issues of political transition. Currently, a large percentage of the first year intake to engineering programs in South Africa has some degree of under-preparedness and the level of under-preparedness is quite high in some cases. Consequently, failure rates are high, many students do not achieve their full potential and many do not derive full benefit from the resources made available to them.

Over the years, various measures have been implemented to address these issues. However, the complex nature of under-preparedness, combined with time and resource constraints, make it difficult to be sure that the implemented measures are dealing with root issues and/or whether or not they are as effective as they might be. The current study is an effort to provide deeper insight that will address these uncertainties. The basic concept behind the study is to start with what we know most about – engineering competency – and then to work backwards towards a deeper understanding of the aspects of under-preparedness that require most attention. This paper develops a definition of engineering competency expressed in the form of a taxonomy. Follow-up papers will explore the issue of under-preparedness in engineering education.

2. Objective and Methodology

The aim of this paper is to provide a generic description of engineering competency that will serve as an effective reference to guide the design and implementation of curricula and remediation measures for engineering education and training programs where under-preparedness is a problem. No serious attempt is made here to analyze under-preparedness as a basis for how the reference should be established or what form it should take. The uncertainties about the nature of under-preparedness make such an analysis difficult. Rather, the approach adopted is simply to find as many relevant perspectives on engineering competency as possible, to analyze them and integrate them appropriately into a single expanded perspective. In order to have a rational basis for doing this, the following criteria were used.

- Relevance: Any description of engineering competencies that might usefully inform curriculum design and remediation measures is relevant. Clearly, any perspective emanating from the profession or from engineering education circles is relevant. It will be evident from the introduction that the problem with under-preparedness is more than just a learning issue – it is a performance issue. Accordingly, perspectives on performance in general and on engineering performance in particular are relevant.
- Significance: The significance of any aspect of competency must be determined on the basis of the extent to which it is supported by properly researched evidence, or by the degree to which it is accepted in the discipline area, or by the degree of importance bestowed on it by professional bodies.
- Personal Judgment: In a few instances, significance was not attributed according to the above criteria but was based on the exercise of personal judgment emanating from years of experience in the engineering work place, in the academic environment and with under-prepared engineering students. This was done judiciously and only where an aspect of competency was considered to be particularly important from the point of view of under-preparedness.
- Detail: A combination of breadth and detail – such as is found in a dictionary – is too ambitious and of questionable usefulness at this stage of the study. Breadth of scope is essential, but the detail must be condensed and arranged into well defined, generic categories. To facilitate an understanding of the whole subject, the number of categories used should be relatively small and they should be arranged in a way that makes intrinsic and relational sense.

A search of the literature reveals a number of perspectives on engineering work and competency – each one shaped by the context from which it emerges. Eight perspectives were considered to be relevant and significant and a ninth was developed in this study. Table 1 presents the taxonomy of engineering competency that has been developed by examining and integrating these perspectives. The reader interested in understanding the rationale behind the taxonomy is referred to sections 3 to 6 below. Section 3 describes and explains each of the perspectives that have been developed or extracted from the literature. The significance of the various competencies identified in these perspectives is examined more closely in section 4. Section 5 explains the new taxonomy in detail. A discussion and conclusion follow in Section 6.

3. The Nature of Engineering Work and Competency

Generic Descriptions of Work

Tables 2 and 3 present two generic descriptions of work. The first of these is derived from the field of performance management and the second was developed in the current study and is more oriented towards understanding engineering work.

The taxonomy of major performance components presented in Table 2 is an augmented version of the taxonomy developed by Campbell et all[1]. The nature of the taxonomy is strongly influenced by the concerns of the disciplines from which it emerges – human resource management, industrial psychology and business management. The focus of the taxonomy is work performance and the need to understand how different aspects of individual performance determine effectiveness in a job. Nine categories are shown in Table 2 – the performance of tasks (job-specific and non-job-specific), communication, productive personal behaviours (demonstrating effort, maintaining personal discipline, adaptive performance) and productive interactions with people (in teams and with peers, in supervision and leadership, in managerial and administrative situations).

The nine performance components are not all relevant to every type of job. However, Campbell et al claim that their categories (the first eight in Table 2) are sufficient to describe, at a generic level, all aspects of work performance that may be relevant for any job. Williams, in his review of the related literature[2], suggests 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. He also noted terminology in the literature that differed from Campbell's as well as differences in emphasis and some differences in approach. On examination, however, he concluded that the differences were not very significant and that Campbell's categories plus 'adaptive performance' were an adequate general description of the major components of work performance.

A different taxonomy is presented in Table 3. This was developed in the current study as a basic framework for describing the different aspects of an individual's work. The rationale here is that different types of work function require different profiles of competencies. For example, the competency mix for initiating work is different from the one needed for acquiring resources. The work functions in the taxonomy 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 activities although their extent and complexity will be very different.

The taxonomy in Table 3 takes cognizance of the important distinction between 'line functions' and 'support functions'. In organizational terms, the former have to do with the 'production line' or the core business of an enterprise (production, service or trading) that is directly involved in earning income for the business enterprise. It is useful to make the same kind of distinction when thinking about an individual's job description and to recognize core functions and support functions. Five generic line or core job functions are recognized – initiating work, planning it, acquiring resources, performing sub-tasks and integrating the results of sub tasks. 'Support functions' have to do with supporting the line functions and facilitating their smooth operation. Again five categories are recognized – managing one's work, evaluating effectiveness (productivity, profitability, quality, service, impact), interacting with people, communication and "house keeping" or resource management. The comprehensiveness of these ten categories has still to be formally tested.

Generic Descriptions of Engineering Work

More detailed descriptions of the generic content of engineering work may be obtained from the documentation produced by various professional and national bodies for accrediting engineering education programs. These documents present compilations of required educational outcomes and so define the competencies learners are expected to possess in order to be competent engineering graduates. To achieve this objective, the documents must be based on conceptions of engineering work that are accurate and comprehensive in scope but generic in detail.

Table 4 presents summaries of the categories of outcomes found in the documentation published by ECSA[6] (Engineering Council of South Africa) and ABET[7] (Accreditation Bureau for Engineering and Technology). Also included in the table are seven aspects of engineering work that a recent paper identifies as being of particular importance in engineering work in the near future[8]. Not surprisingly, a high degree of consensus is evident in the Table and can be confirmed by referring to the documentation from accrediting bodies[9-11] in Canada, Australia, United Kingdom and New Zealand.

The Engineer in the Work Place

Four further perspectives on engineering work may be obtained by considering information drawn directly or indirectly from the engineering work place. Table 5 presents ten different generic settings in which an engineer may work during his/her career – analysis, design, testing, development, sales, research, line engineer/manager, project engineer/manager, consulting, and teaching. The categories are those presented by Landis[12] in his widely respected book on studying engineering. The brief descriptions given in the Table for each type of setting provide a view on engineering work that complements the other perspectives that have been given.

Further perspectives on engineering work emerge from the many surveys[15-18] that have been conducted to discover which competencies engineering employers look for in engineering graduates. Only two examples of these surveys will be considered to illustrate the nature of the information they provide. A survey[18] of over 1000 US employers rated the skills graduates need on a scale 1 to 5 (from least to most important). Their findings were as follows:-

a)	Oral communication skills	4.7
b)	Interpersonal skills	4.6
c)	Teamwork skills	4.5
d)	Flexibility	4.3
e)	Analytical skills	4.3
f)	Written communication skills	4.3
g)	Proficiency in field of study	4.1
h)	Leadership skills	4.1
i)	Computer knowledge	3.9

The second example is a recent study conducted by de Lange[19] in South Africa. Adopting a procedure that had been well established by other workers[15], 'non-technical' competencies (also termed 'critical cross-field outcomes') that had been identified as being potentially relevant were grouped into appropriate clusters. Table 6 presents the clusters and the associated competencies that formed the basis of the survey questionnaire used in the study. The results of the survey are also shown in the Table.

From exposure to surveys of these kinds over many years of teaching introductory engineering, Landis[12] lists the top six factors to which employers refer, in his experience, when considering a graduate engineer for employment. They are as follows:-

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

A Competency Model for Technical Professionals

The perceptions of employers and experienced practitioners are a very significant resource of information. The four perspectives described in the previous section were based directly or indirectly on the results from work place surveys. A different method for soliciting information from the work place has been used for over twenty years by the McBer Consulting Agency[3]. Their methods and findings have been published in a book entitled "Competency at Work: Models for Superior Performance."[20] The work is widely respected[3]. The motivation for the Agency's work is selection of personnel and the need for objective measures to distinguish between superior performers and ordinary performers. Their approach is to develop a competency model for a particular job by identifying superior performers in that job, interviewing them and comparing the findings with those from interviews of other performers. The interviews are conducted by experienced human resource investigators trained in a formalized methodology that has been developed by the Agency over the years. Their task is to identify characteristic behaviours of superior performers and to describe each one in the form of a short narrative description along with measurable behavioural indicators. For example, the eight behavioural indicators identified as effective measures of the competency 'self control' are summarized as 'losses control', 'avoids stress', 'resists temptations', 'controls emotions', 'responds calmly', 'manages stress effectively', 'responds constructively', 'calms others'. Once the set of distinguishing competencies and the related behavioural indicators have been identified, they are arranged into relevant clusters of competencies and this forms the competency model for the particular job.

The experience and data that has been gathered is impressive. Over a span of twenty years, more than 100 trained investigators have developed 286 competency models in over 20 countries. The models cover technical/professional jobs 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'[21]. Models for technical professionals have been developed for software developers, engineers and applied research scientists.

Drawing on this breadth of experience, generic competencies and behavioural indicators were extracted from the models and arranged as 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 behavioural indicators. The dictionary is summarized in Table 7. 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 defines a generalized competency model for each of five different job types – technical professional, human service, entrepreneur, sales/marketing/trading, and management. It claims that each generalized model describes all jobs of each type in general but none in particular. Their competency model for technical professionals is presented in Table 8. It must be noted that the orientation of the model is the identification of superior performers and this must be taken into account when referring to it.

4. Discussion

The taxonomy developed in this paper is intended to be a reference for informing the design and implementation of remedial measures that address under-preparedness in entrants to engineering programs. As explained in the methodology, the first step in this development was to find as broad a range of relevant perspectives as possible. The perspectives found show both much common ground and much variety. The next step in the study was to extract the significant elements of each perspective and to integrate them into the required taxonomy using the stipulated criteria as a guide.

The perspective presented in Table 2 – the taxonomy of major performance components – is the most general and so will be considered first. Williams[4] suggests that it provides a reliable framework for making sure that no aspect of work performance is overlooked when analyzing the nature of any particular job. This framework is used in this study as a basis for defining the basic categories – or major areas of proficiency – by which the new taxonomy is organized. The nine performance components that make up this framework are, however, re-arranged and/or re-named. The first category (job-specific task proficiency) is termed engineering-specific work and the second (non-job-specific task proficiency) is termed non-engineering-specific work. The categories of supervision-leadership and management-administration are recognized as specific instances of non-engineering-specific work.

The distinction between engineering-specific work and non-engineering-specific work is important to make even though it involves some deviation from Campbell's original definitions. It incorporates the distinctions made by Campbell but goes beyond them in order to distinguish between specialist work (engineering work) and non-specialist (any other kind of work an engineer might do). Further discussion on this issue is delayed until other perspectives have been considered.

The other categories in Table 2 require little comment. 'Communication' and 'adaptive performance' feature very strongly in all the other perspectives and are retained in the new taxonomy as major proficiency areas. However, 'facilitating peer and team performance' is recognized as part of a wider category termed 'inter-personal interactions'. The categories of 'demonstrating effort' and 'maintaining personal discipline' are both seen as issues that fall within the wider category of 'personal dispositions'. It should be noted that the latter two aspects of work performance are not identified in any of the other perspectives.

The perspective in Table 3 – a taxonomy of work functions – recognizes ten different kinds of work function – five 'core' functions and five 'support' functions. Three of the support functions – 'managing work', 'communication' and 'interacting with people' – clearly fall into categories already defined. 'Evaluating effectiveness' is implicit in aspects of other perspectives but is identified in this taxonomy as a concern that things be done effectively. Such a concern is often noticeably lacking in some under-prepared students and so is particularly significant. 'Housekeeping' or paying attention to resources (both one's own as well as those made available) is both a competency and a disposition. It 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 competency is not mentioned in the other perspectives but is extremely relevant to many under-prepared learners, some of whom have very little real awareness of the importance of these issues.

The other perspectives extracted from the literature do not identify the core functions as explicitly as does Table 3. However, these functions are implicit in many of the perspectives and some are mentioned specifically in descriptions of the design process (eg in the footnote to Table 5 and in the details about design given in engineering accreditation documents[6]). Again, many under-prepared learners have little practical awareness or experience of the different stages of executing a large task or project. Accordingly, these functions are significant and should be included explicitly in the new taxonomy.

Table 5 – engineering job functions – provides a perspective that is similar to the one just described except that it is less generic and describes the different kinds of work situations that engineers may find themselves in. The focus on specific kinds of engineering work rather than on generic competencies engineers should possess is interesting. This focus is taken up in the new taxonomy as a way of grounding the description of engineering competency in the work engineers actually do. Another dimension of engineering competency becomes evident as a result of applying this approach – namely that engineers whose core tasks involve both specific and non-specific engineering work must be competent to integrate the two effectively. Accordingly, the category 'engineering mixed with other work' is recognized as being important. The instances of this given in Table 5 are management, administration, leadership, supervision, project work, sales, consulting and teaching. Engineering entrepreneurship should be added to this list. These kinds of mixed engineering work are distinguished from 'specialist engineering work' – analytical, design and investigation. According to Table 5, the latter – engineering investigation work – should include testing, development and research.

The perspective presented in Table 4 – outcomes specified by engineering education accreditation documents – is obviously of crucial importance in the new taxonomy. What is perhaps surprising is that it does not incorporate all of the competencies mentioned in the other perspectives. This is partly due to its interest in technical competencies, partly to a specific focus on graduate competency rather than professional competency and partly to the nature of accreditation documents. It is also partly due to the traditional assumption that the role of an engineering education program is to focus on technical development and that non-technical competencies are best developed in the context of the work place rather than in a tertiary learning institution.

The last assumption has some validity. However, increasing attention on non-technical competencies is being required of engineering programs, as is evident from even a cursory look at Table 4. In addition, many studies have been conducted to solicit information from the work place about the non-technical competencies that employers look for in graduates (see Table 6 and section 3.3). These observations are a strong argument not just for the importance of non-technical competencies in an engineer – but also for the need to give significant attention to their development during tertiary education.

All nine perspectives consider non-technical competencies to be important. Spencer and Spencer, after presenting the McBer competency model for technical professionals, specifically remark on this in the following way.

> "Technical/professionals deal primarily with problems concerning machines, numbers, or physical processes. Given this focus it is intriguing that fully one quarter of the distinguishing characteristics (of superior performers) fall into the interpersonal and managerial clusters. The best 'hard science' technical professionals use interpersonal skills and teamwork to accomplish their technical jobs."[21]

Table 6 illustrates the perspective that employers and practitioners have about the non-technical competencies they would like to see in graduate engineers. Apart from the category of 'self-management and personal style', the information in the Table compliments the perspectives already presented and gives more detail but does not introduce anything new. 'Self-management and personal style' correspond to the 'personal qualifications' that Landis regards as being important ((j) of section 3.3). These 'personal dispositions' include maturity, initiative, enthusiasm, poise and appearance – issues that are very relevant to some under-prepared students.

The dispositions, abilities and understandings listed in Table 8 – the competency model for technical professionals – cover the same ground (and more) as do the non-technical competencies just discussed. What is different, however, is the research method and the focus on distinguishing between superior and ordinary performers. The list of distinguishing characteristics, therefore, points to factors that have been shown to be particularly significance for effective engineering performance. As such, all these characteristics need to be included in the new taxonomy. However, they should be included not so much as required competencies but as dispositions that are particularly 'productive' if they are present in an engineer's personal repertoire.

5. A New Taxonomy of Engineering Competency

The various perspectives and aspects considered in the above discussion have been drawn together and integrated into the taxonomy presented in Table 1. Seven 'major areas of proficiency' are recognized – engineering-specific work, non-engineering-specific work, communication, inter-personal interactions, personal dispositions, adaptive dispositions, and particularly productive dispositions. The first six of these are the categories of Table 1, modified as explained in the discussion. The seventh area – 'particularly productive dispositions' – covers the abilities, dispositions and understandings found in Table 8. For the most part, the wording in Table 1 is drawn directly from Tables 2 to 8. Some editing, re-arrangement and expansion was necessary particularly when there was more than one description for the same set of competencies. The thinking behind these integrating decisions will become evident in the explanatory review of the new taxonomy that follows.

Engineering-Specific Work:

A distinction is made between 'specialist engineering work', 'engineering mixed with other work' and 'general engineering work'. The rationale behind using the first two categories was given in the discussion. Specialist engineering work is subdivided into analytical, design and investigative work areas as suggested in the discussion. The need for the third category – 'general engineering work' – becomes evident when it is recognized that some of the competencies described in the various perspectives are relevant to all three specialist areas as well as to 'engineering mixed with other work'. These general aspects of engineering work have to do with performing the different stages of any task or project (the core functions of Table 3), using general engineering tools and techniques (items 2 and 5 in Table 4), evaluating effectiveness (item 7 in Table 3) and handling information (item 2 in Table 6 and item 5 in Table 4). The category of 'engineering mixed with other work' focuses specially on competencies required when integrating engineering work with other kinds of work as explained in the earlier discussion.

Non-Engineering Specific Work:
Three subdivisions are made in this category – general, supervision/leadership and management/administration. The 'general' subdivision incorporates the competency groupings of performing tasks outside of one's job description (item 2 in Table 2), self management (item 4 in Table 6 and (j) in section 3.3), resource management (item 10 in Table 3) and team work/peer support. The latter is 'required work' in modern engineering environments and so is included in this proficiency area. The inter-personal skills needed for this work are also included in the proficiency area of inter-personal interactions.

Communication and Inter-Personal Interactions:
Both of these proficiency areas are recognized by all the perspectives as being important. Two groupings of competencies are recognized for the latter – one for personal interactions in general and the other for the interactions that contribute to the effectiveness of teamwork.

Personal Dispositions:
Personal dispositions that are important for engineering competency are divided into two categories – 'general' and 'discipline'. The dispositions in the 'discipline' category include 'maintaining personal disciplines' (item 5 in Table 2), and critical awareness in two areas – professional ethics and the impact of engineering activities (items 9 and 10 in Table 4). Other aspects of required personal dispositions as identified by the various perspectives have been grouped together under 'general'. These include Landis' and de Lange's self-management and personal styles, Campbell's 'demonstrating effort', ECSA's taking responsibility and ABET's interest in contemporary issues.

Adaptive Dispositions:
Three related categories have been recognized in this proficiency area – self-development, life-long learning (item 9 in Table 2 and item 8 in Table 4) and change management (item 12 in Table 4). Grouped under 'self-development' are the competency groupings of self-awareness (item 13 in Table 4), learning skills and being disposed to developing competencies in general (item 8 in Table 4) and in critical areas (Table 8). Learning and the motivation to learn effectively are specific aspects of life-long learning and have been highlighted because of their particular importance to many under-prepared learners.

Particularly Productive Dispositions:
As explained in the discussion, the distinguishing characteristics of superior performers have been included as productive dispositions worth developing. The complete competency dictionary summarized in Table 7 is interesting but only the characteristics listed in Table 8 have been included. (Fuller descriptions of these characteristics have been extracted from the original reference and included in the new taxonomy.)

6. Conclusion
The concern of this paper has been to develop a taxonomy of engineering competency that can serve as a reference to inform the design and implementation of curricula and remedial measures that deal with under-preparedness in entrants to engineering programs. The taxonomy that has been developed is presented as Table 1. That the taxonomy satisfies the requirements for being the reference needed is supported by the following points.

Its comprehensiveness of scope is assured for two reasons. Firstly, it includes perspectives that, in regard to their particular interests, need to be and have been shown to be comprehensive in scope. These include the taxonomy of major components of work performance (Table 2) and the conceptions of engineering competency held by professional accrediting bodies (Table 4). Secondly, a wide range of perspectives was considered. These include views of work and competency from the perspective of human resource management, professional bodies responsible for accreditation of engineering programs, educators experienced in introducing engineering to students, educators experienced in teaching under-prepared learners and engineering employers and practitioners in the work place.

The reliability and relevance of the competencies and dispositions included in the taxonomy are supported by the fact that, in most cases, only perspectives that enjoyed a strong basis of support were integrated into the taxonomy. The level of detail in the taxonomy is generic. In the case of technical competencies in particular, less detail is included than is found in engineering education accreditation documents.

Clearly the taxonomy goes beyond giving a list of the competencies a single engineer should possess to be considered competent. Only a small proportion of mature engineers will possess all the characteristics listed in Table 1. Rather, the taxonomy gives a comprehensive list of generic competencies that are important in the profession. To some degree the taxonomy over-emphasizes aspects considered to be of special relevance to under-prepared learners. Otherwise, the taxonomy is useful in its own right as a generic description of engineering competency and is broader than other perspectives found in the literature.

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TABLE 1: A Taxonomy of Engineering Competency

(References and wording are taken from Tables 2-8)

Major Areas of Proficiency	Sub Categories	Competency: An Ability to …
1) Engineering-Specific Work	General Engineering Work	Perform the different aspects of any engineering work or task namely initiating and planning the work/task, acquiring the resources needed, performing sub-tasks and evaluating and synthesizing results.
		Use appropriate engineering and computer methods, skills and tools and properly assess, analyze and interpret the results they yield.
		Evaluate effectiveness, productivity, profitability, quality, service, impact or implications of any aspect of work done or planned and a disposition to do so.
		Arrange, sort, retrieve and properly assess data, knowledge and ideas.
	Specialist Engineering Work	Perform **analytical work** to solve existing and anticipated engineering problems and model relevant systems by (1) applying knowledge of mathematics and the natural, engineering and computational sciences, and (2) identifying, assessing, formulating and solving convergent and divergent engineering problems in a creative and innovative way.
		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.
		Plan and perform **investigations** to (1) **test** that a design or product meets specifications, (2) **develop** products, components, systems or processes, or (3) **search for new knowledge** that can be applied for the advancement of engineering practice.
	Engineering Mixed with Other Work	Integrate specialist engineering work appropriately with work relating to core functions, management, administration, supervision, projects, sales, consulting, entrepreneurship or teaching in order to achieve the broader aims of the business enterprise or stated objectives.
2) Non-Engineering-Specific Work	General	Perform tasks and execute behaviours not specific to one's particular job.
		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 dealt with appropriately.
		Support and help peers and facilitate group functioning by being a good model, keeping the group directed and reinforcing participation by other group members.
		Ensure that the resources and capacity to do good work are maintained, sustained, and, where necessary, developed further.
	Supervision, Leadership	Influence the performance of subordinates through interpersonal interaction and influence, modeling, goal-setting, coaching and providing reinforcement.
		Function as a supervisor in the 'line production' activities of the enterprise at the appropriate designated position in the supervision hierarchy.
	Management, Administration	Articulate goals for a unit or enterprise, organize people or resources to achieve these, monitor progress, help to solve problems or overcome crises that stand in the way, control expenditures, and represent the unit in dealing with other units or clients.
		Manage a project and ensure that it is completed successfully, on time and within budget.
3) Communication	General	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 and the larger community.
4) Inter-personal Interactions	General	Interact effectively and positively with colleagues, clients, superiors, subordinates, engineering audiences and the larger community.
		Function effectively on multi-disciplinary teams through personal contributions and interactions with others that enhance their contributions.
Dispositions	See continuation of Table 1	

TABLE 1 continued: A Taxonomy of Engineering Competency

Major Areas of Proficiency	Sub Categories	Ability, Disposition or Understanding
5) Personal Dispositions	General	Agreeable personal style, characteristics and self-management including maturity, initiative, enthusiasm, poise, appearance, values, goals, outlook and motivation.
		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.
		Disposed to taking responsibility within own limits of competence.
		Interest and knowledge in contemporary issues.
	Discipline	Disposed to maintaining personal disciplines and avoiding negative behaviours.
		Being critically aware of the need to act professionally and ethically.
		Being critically aware of the impact of engineering activity in a global/social setting.
6) Adaptive Dispositions	Self-Development	Disposed to improving personal competencies in general.
		Understands nature and importance of effective learning skills and is able to apply them.
		Able to assess one's own performance effectively and accurately.
		Disposed to improving critical knowledge, skills and dispositions in an effort to sustain or improve one's reputation and advancement prospects.
	Life-long Learning	Understands the requirement to maintain continued competence.
		Able to and disposed to engage in independent and interdependent life-long learning through well developed learning skills.
	Change Management	Able to manage the impact of change effectively and flexibly, and to engage in new learning in coping with change.
7) Particularly Productive Dispositions (listed in order of importance as expressed in Table 8)	Achievement Orientation	Works to meet required standards but also creates own measures of excellence.
		Disposed to improve performance or improve morale, revenues or customer satisfaction by making specific changes in the system or in own work methods.
		Sets and acts to reach challenging goals for self or others*.
		Innovates.
	Impact and Influence	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.
		Shows concern with professional reputation.
	Conceptual Thinking	Recognizes key actions and underlying problems by observing discrepancies, trends and inter-relationships, crucial differences, past discrepancies.
		Able to condense large amounts of information in a useful manner.
		Makes connections and patterns by pulling together ideas, issues and observations into a single concept and identifies key issues in complex situations.
	Analytical Thinking	Anticipates obstacles, breaks problem apart systematically, makes logical conclusions, sees consequences and implications.
	Initiative	Persists in problem solving when things do not go smoothly. Exceeds job description. Addresses problems before asked to. Creates opportunities.
	Self-Confidence	Expresses confidence in own judgement. Sees self as a causal agent, prime mover.
		Seeks challenges and independence, welcomes challenging assignments, seeks additional responsibility, states own position clearly and confidently.
	Interpersonal Understanding	Understands attitudes, interests, needs of others and is good at discerning unspoken thoughts, concerns or feelings.
	Concern for Order	Seeks clarity of roles and information, checks quality of work/information, keeps records and an organised workplace, monitors data, projects and the work of others.
	Information Seeking	Asks questions, personally investigates, digs deeper, calls or contacts others, does research, uses own ongoing systems, involves others.
	Teamwork and Cooperation	Genuinely values others' input and expertise and is willing to learn from others.
		Empowers others, encourages those who perform well and gives them credit.
	Expertise	Applies technical knowledge to achieve additional impact, goes beyond simply answering a question and helps resolve others' technical problems.
		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.
	Customer Service Orientation	Seeks information about the real, underlying needs of the client, beyond those expressed initially, and matches these to available (or customised) products or services.

* 'Challenging' means there is a 50-50 chance of actually achieving the goal – it is a definite stretch, but not unrealistic or impossible'.[23]

TABLE 2: A Taxonomy of Major Performance Components
(extracted from Campbell et al[1] except for item 9)

	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 behaviours that distinguish the substantive content of one job from another.
2	Non-job-specific task proficiency	Proficiency in performing tasks or executing performance behaviours which are not specific to one's particular job – eg, 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 behaviours – 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 inter-personal 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,'[24] 'capacity to engage with new learning in coping with change,'[25] 'developing oneself'.[5]

Table 3: A Taxonomy of Individual Work Functions

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 organisation 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 analysed and understood. The work to be done must be broken down into sub-tasks that are appropriate, manageable, well defined and properly prioritised 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 organisation, 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 sub-tasks: The worker must bring his/her knowledge and the acquired resources to bear effectively in order to accomplish each of the required sub-tasks.
	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 organisation, the market, society and the environment. This involves the examination of and the exercise of judgement 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 organisation.
	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 4: Outcomes Specified in Relevant Engineering Education Documents.

ECSA Accreditation Requirements[6] A graduate must be competent to ...	ABET accreditation Requirements[7]	Outcomes Specially Important in the Future[8]
1) Identify, assess, formulate and solve convergent and divergent engineering problems.	Able to identify, formulate and solve engineering problems.	Critical / creative thinking and problem solving
2) Apply knowledge of mathematics, science and engineering sciences to solve engineering problems.	Able to apply knowledge of mathematics, science and engineering.	----
3) Perform creative procedural/non-procedural design and synthesis of components, products or processes.	Able to design a system, component or process to meet desired needs.	Integrative and global thinking skills
4) Plan and conduct investigations and analyse, interpret and derive information from data.	Able to design/conduct experiments and analyse and interpret data.	----
5) Use appropriate engineering and computer methods, skills and tools and assess the results they yield.	Able to use the techniques, skills and tools needed for engineering practice.	----
6) Communicate effectively (in writing and orally) with engineering audiences and the larger community.	Able to communicate effectively.	Communication skills.
7) Work effectively as an individual in teams and multi-disciplinary environments.	Able to function on multi-disciplinary teams.	Interpersonal and teamwork skills.
8) Engage in life-long learning through well-developed learning skills and understand the requirement to maintain continued competence.	A recognition of the need for and the ability to engage in life-long learning.	Independent and interdependent life-long learning skills.
9) A graduate must be critically aware of the need to act professionally and ethically and to take responsibility within own limits of competence.	An understanding of professional and ethical responsibility.	----
10) A graduate must be critically aware of the impact of engineering activity on society and the environment.	The broad education necessary to understand the impact of engineering solutions in a global/social context.	----
11) ----	Knowledge of contemporary issues.	----
12) ----	----	Change management skills.
13) ----	----	Self-assessment skills.

TABLE 5: Engineering Job Functions
Extracted from Landis[13]

	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.
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.

* Landis[14] outlines the design process as follows:
(1) Customer need or opportunity, (2) Problem definition/specification,
(3) Data and information collection, (4) Development of alternative designs,
(5) Evaluation of designs and selection of the optimum,
(6) Implementation of the optimum design.

Table 6: Non-Technical Skills Important for Engineering Graduates[19]

(Results of the survey are indicated by Importance Ranking (IR) and %Relative Importance (RI.))

	Ranked in order of perceived importance	Other Skills in Questionnaire *
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) (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, Prioritising, Reporting, Computer application, Recording, Collection.	Retrieval, Research, Organisation, Scheduling, Synthesising, 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%)	Co-operates, Is responsive, Is helpful, Co-ordinates, Is compatible, Has group process skills, Is tactful, Is even tempered, Is sensitive to cultural diversity, Leads and manages, Recruits ideas, Summarises.	Puts people at ease, Negotiates, Solicits, Has social commitment, Is hospitable, Is outgoing, Supervises, Praises, Counsels, Has empathy, Is persuasive.
7) Organisational Effectiveness and Teamwork	**The ability to effectively contribute towards the successful completion of a set of organisational goals.**	
(IR = 5) (RI = 85%)	Meets deadlines, Works to schedule, Is goal orientated, Assumes responsibility, Puts theory into practice, Works under pressure, Prioritises, 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.

Details obtained from the author privately: see also de Jager et al [26]

Table 7: A Summary of the McBer Competency Dictionary[21]

Distinguishing Competency Cluster	Competency Group*	Competency	Number of Behavioural Indicators
1) Achievement and Action	Achievement Orientation (ACH)	Intensity and completeness of achievement orientation.	9
		Achievement impact.	7
		Degree of innovation.	5
	Concern for Order, Quality, Accuracy (CO)	Concern for order, quality and accuracy.	9
	Initiative (INT)	Time dimension.	11
		Self-motivation, amount of discretionary effort.	8
	Information seeking (INFO)	Information seeking.	8
2) Helping and Human Service	Interpersonal understanding (IU)	Depth of understanding of others.	7
		Listening and responding to others.	7
	Customer service orientation (CSO)	Focus on client's needs.	13
		Initiative (discretionary effort) to help or serve others	7
3) Impact and Influence	Impact and influence (IMP)	Actions taken to influence others.	10
		Breadth of influence, understanding or network.	9
	Organizational awareness (OA)	Depth of understanding of organization.	8
	Relationship building (RB)	Closeness of relationships built.	9
4) Managerial	Developing others (DEV)	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 (DIR)	Intensity of directiveness.	11
	Teamwork and cooperation (TW)	Intensity of fostering teamwork.	9
		Size of team involved.	6
		Amount of effort or initiative to foster teamwork.	6
	Team leadership (TL)	Strength of leadership role.	9
5) Cognitive	Analytical thinking (AT)	Complexity of analysis.	7
		Size of problem addressed.	5
	Conceptual thinking (CT)	Complexity and originality of concepts.	8
	Technical, professional, managerial expertise (EXP)	Depth of knowledge.	8
		Breadth of managerial experience.	7
		Acquisition of expertise.	5
		Distribution of expertise.	7
6) Personal Effectiveness	Self-control (SCT)	Self-control.	8
	Self-confidence (SCF)	Self-assurance.	8
		Dealing with failure.	6
	Flexibility (FLX)	Breadth of change.	8
		Speed of change.	5
	Organizational commitment (OC)	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.	

* Reference codes for each competency group are given in brackets.

Table 8: Summary of the Generalized Competency Model for Technical Professionals[22]

Competency	Relative 'Weight'*	Behavioural Indicators (These are described more fully in Table 1)
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 judgement. Seeks challenges and independence.
7) Inter-personal 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.

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