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Innovation as a Meta-Attribute for Graduate Engineers*

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This paper reviews the attitudes, skills and knowledge that engineering innovators should possess. It critically analyses and compares sets of graduate attributes from the USA, Australia and Malaysia in terms of which of these relate to the ability to innovate. Innovation can be described as an integrative, meta-attribute that overarches most of the other graduate attributes. Due to the 'graduate attribute paradox', it is shown how meeting the stated attributes of graduates by industry does not necessarily satisfy the requirements of industry. It is argued that the culture of the engineering school is an important influence on fostering innovation in engineers.

INTRODUCTION

INNOVATION AND ITS impact on national wealth creation within a globalized economy are currently high on the political agenda in many countries. National and regional levels of government, professional bodies and various industry groups have initiated and are supporting programs to foster innovation in industry and in education [e.g. 1–3]. Steiner [4] argues that all engineering students have the potential for innovation but in order to achieve this potential they must choose to be nonconformist, commercially pragmatic, and cooperative. For her, this means breaking out of the engineering paradigm and operating 'unscientifically in the public world rather than theoretically and scientifically in the special world of engineering.'

If we are to foster the ability of engineering graduates to be innovative and entrepreneurial, we must place this in the broader context of the objectives of baccalaureate programs in engineering and any subsequent processes of personal or professional formation. During the mid 1990s engineering education in the USA and Australia each underwent a major review involving the agencies that accredit engineering programs in each country, ABET [5] in the USA and the Institution of Engineers in Australia (IE Aust) [6]. The IE Aust is not only the accrediting organization but also the professional body for engineering in Australia covering all disciplines. Other countries, including Malaysia [7], also conducted national reviews of engineering education and more recently Germany has began to review its programs.

The result has been a shift in the basis for accrediting courses from one focused on inputs, content and processes to one based primarily on the achievement of outcomes. These program outcomes are expressed in terms of a set of required graduate attributes. Typically these attributes recognize not only the need for technical competence but also the necessity for broader abilities, including such things as teamwork, ethical and professional responsibility, social and sustainability awareness, and the capacity to undertake life-long learning. These lists of graduate attributes were not developed specifically with innovative or entrepreneurial ability in mind, but rather in response to the broader, emerging demands on future engineers. Given the current interest in innovation, it is timely to critically analyse these graduate attributes to see if they include or embody innovation and entrepreneurship.

INNOVATION AND ENTREPRENEURSHIP

The terms 'innovation' and 'entrepreneur' are not easy to define as absolute concepts but the following descriptions highlight some of the defining characteristics of each and their inter-relationship. Williams (1999) [8] draws a distinction between creativity as 'finding, thinking up and making *new* things' (knowledge for its own sake) and innovation as 'doing and using *new* things' (creation of new wealth) and entrepreneurs are 'catalysts for change by converting opportunities into marketable realities.' IPENZ [3] state that 'innovation is the act of creating something new and worthwhile, entrepreneurship is the act of carrying an innovation to market in a commercial manner'. It is often about taking an idea that is obvious in one context and applying it in a not so obvious way in a different context [9].

The definition of innovation used in 3M is 'new ideas plus action or implementation which results in an improvement, gain or profit' [10]. They

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identify three types of innovation: new market or industry, changing basis of competition and line extension. Given the blurring of innovation and entrepreneur in their definition, 3M have adopted the word 'inventorpreneur' to describe their outstanding innovators. Such a person 'invents or creates a new product that fulfils a defined need; promotes the new opportunity or product; manages, organises and assumes many risks in establishing a new business based on that product'.

Contemporary accounts of innovation stress that it is not about brilliant individuals as much as it is about creating environments that foster innovation [9]. An innovative environment has been characterized as one that is trusting, is open to new ideas and alternative approaches to solving problems and exploiting opportunities, operates in an environment of adaptability, operates in an environment of flexibility, is goal-directed with a sense of purpose, demonstrates that innovation is valued and recognizes innovative achievements [11].

Traits and abilities of innovators and entrepreneurs

While much of the literature on innovation is quite recent, over thirty years ago Gregory [12] in the UK generated a set of educational objectives for the preparation of engineers based on the earlier work of de Simone in the USA. These are presented in Table 1.

It is interesting to compare these with more contemporary lists of characteristics of innovators. Based on a case study of the managers of a design consultancy specializing in product and process innovations, Steiner [4] suggests that innovators should be 'energetic, enthusiastic, competitive, innovative, thrive on change, diversity and challenge and be able to live with uncertainty'. They must be competent, credible and effective in their area of professional expertise, but be able to blend these technical skills with business acumen. They require excellent people skills, including communication skills and managerial skills. But in addition to these *skills* and *qualities* they also require a set of *attitudes* that action the skills. These include a challenge-seeking attitude, being a genuine team player while also being self-directed and autonomous, responding positively to external pressures not retreating from them, a desire to keep learning (and not imagining they know it all), be interested in the commercial aspects, show 'intellectual flexibility' and to be able to keep striving but to also accept defeat.

In a similar vein, the 3M company looks for people with certain traits as indicators of their potential to be innovators, as listed in Table 2.

Although the terminology differs, there is a remarkable similarity between the list of educational objectives for innovators from the 1960s (Table 1) and the more recent lists of traits of innovators. This similarity suggests that the underlying factors have been known for some time and have not changed, despite the significant changes that have occurred in technology, business and society in the interim.

The characteristics of the innovator and the entrepreneur overlap. Williams [8] describes entrepreneurs as people who have both the will (e.g. desire or motivation) and skill (e.g. the ability) to project an idea or scheme into the future by backing their judgment with innovative action and persistence in order turn that idea into reality. They tend to be creative individuals with a never-ending supply of ideas and schemes; action people who make things happen; catalysts (initiators of change); aggressively ambitious and highly competitive; moderate risk-takers (not risk averse but not gamblers); self-reliant and independent; resourceful and shrewd; highly tolerant of ambiguity and uncertainty; determined, optimistic and persistent; and very future-oriented. [8]

It must be realized that innovation in practice is

Table 1. Educational objectives in the preparation of engineers [12]

Ability	Specifics
Recognition and formation of problems	Sense of urgency; sensing what is important; multidisciplinary problems; making realistic assumptions; social relevance; relating to other similar problems; asking pertinent questions; thinking in terms of analogies
Ability to use full range of engineering methods	Reliability and other probabilistic-based procedures, optimising techniques, simulation and modelling, iterative procedures, trial and error approaches; gathering information from books, people, nature, experiment; decision-making techniques; metaphorical analogizing; brainstorming
Consciousness of values and costs	Particularly social and economic values; estimating costs; trade-off between capital and operating costs
Appreciation of the process of innovation	The process itself; its importance in enterprise growth; role in the economy
Cognisance of human factors in engineering	Awareness of and start to competence in dealing with them; development of the ability to communicate, sell ideas and understand the motivation of others
Critical point of view	The challenging of presuppositions; keen powers of observation; continual seeking of improvement; insight
Capacity for self-development	Ability to relate self to the world; planning for continuing education; awareness of the psychology of creativity; program for keeping up

Table 2. Innovation traits sought by 3M [10]

Trait	Dimensions
Creative	Inquisitive/asks questions; explorative; looks for solutions; insightful/intuitive; ideas flow easily; visionary
Broad interests	Eager to learn; explores ideas with others; hobbies; multidisciplinary
Problem solver	Experimental style (do it first, explain later); tinkers with things (hands-on); not afraid to make mistakes; willing to explore the unobvious; practical; takes multiple approaches to a problem
Self-motivated/energized	Self-starter/driven; results-oriented; passionate about what they do; accomplished and wants to succeed; sense of humor; sense of contribution, value and purpose; takes initiatives
Strong work ethic	Committed; works in cycles; flexible work habits (not structured); drives towards completion; tenacious
Resourceful	Networks; gets things done through others

Table 3. Comparison of engineering graduate attributes

ABET 2000 EC [5]	IE Aust Graduate Attributes [6]	Malaysian Engineering Education Model [7]
a) An ability to apply knowledge of mathematics, science and engineering b) An ability to design and conduct experiments, as well as to analyse and interpret data c) An ability to design a system, component, or process to meet desired needs d) An ability to function in a multi-disciplinary teams e) An ability to identify, formulate, and solve engineering problems f) An understanding of professional and ethical responsibility g) An ability to communicate effectively h) The broad education necessary to understand the impact of engineering solutions in a global and societal context i) A recognition of the need for, and an ability to engage in lifelong learning j) A knowledge of contemporary issues k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	• An ability to apply knowledge of mathematics, science and engineering • An ability to design and conduct experiments, as well as to analyse and interpret data • An ability to design a system, component, or process to meet desired needs • An ability to function in a multi-disciplinary teams • An ability to identify, formulate, and solve engineering problems • An understanding of professional and ethical responsibility • An ability to communicate effectively • The broad education necessary to understand the impact of engineering solutions in a global and societal context • A recognition of the need for, and an ability to engage in lifelong learning • A knowledge of contemporary issues • An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice • Ability to apply knowledge of basic science and engineering fundamentals • Ability to communicate effectively, not only with engineers but also with the community at large • In-depth technical competence in at least one engineering discipline • Ability to undertake problem identification, formulation and solution • Ability to utilise a systems approach to design and operational performance • Ability to function effectively as an individual and in multi-disciplinary and multi-cultural teams, with the capacity to be a leader or manager as well as an effective team member • Understanding of the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development • Understanding of the principles of sustainable design and development • Understanding of professional and ethical responsibilities and commitment to them • Expectation of the need to undertake lifelong learning, and capacity to do so	• **Global % Strategic** These skills enable students to adapt easily within the borderless world that is experiencing rapid expanding knowledge. • **Industrial** Skills that go beyond the scientific and professional and which are necessary in the advanced phase of the graduate's career. • **Humanistic** These skills help create a balanced engineer with high ethical and moral standards. • **Practical** These enable students to be directly involved with hands-on activities or real-life situations, thus providing the basis for integrating the intra- and inter-engineering and non-engineering knowledge. • **Professional** Such skills cover the technical competency aspects required to perform specific engineering tasks. • **Scientific** These skills enable students to have a firm foundation in engineering science, thus enabling them to realign themselves with the changes in emphasis in the scientific field and to develop an interest in R&D and design.

not determined solely by the skills and attitudes of individuals or even teams. Performance also depends upon the tasks being undertaken and the work environment [13]. Williams [8] challenges the whole notion of defining abilities, asserting that 'entrepreneurship is what entrepreneurs do rather than a list of personality traits.' It is clear that innovation and entrepreneurship are contextual, enacted and holistic activities. Consequently, attempts to extract their elemental parts via a reductionist paradigm for inclusion in a curriculum are likely to fail. Thus, while lists of characteristics like those in Tables 1 and 2 are helpful in understanding these phenomena, they are potentially limited as pedagogical directives.

Graduate attributes for engineers

While there is no universal set of desirable attributes for an engineering graduate, there is a growing consensus globally as to the abilities and skills required of them. This is illustrated in Table 3, which compares the lists of graduate attributes developed by ABET [5], IE Aust [6] and the Board of Engineers, Malaysia [7].

Clearly there is considerable overlap in these lists, most particularly between the ABET and IE Aust. lists. The MEEM tends to cluster many of the elements found in the other two lists. All three lists are about awareness, skills and knowledge. They do not go to the attitudes, values or motivations that permeate the dimensions of the various traits of potential innovators in Table 2 or the attitudes and indeed some of the qualities identified by Steiner [4]. Curiously the list of educational objectives in Table 1, while being substantially about skills and knowledge, does include some specifics that are more attitudinal or value-based.

Most, if not all, of the skills and knowledge required for innovation (Tables 1 and 2) are included in one form or another in each of the three sets of graduate attributes in Table 3. The ability to be innovative is not a separate or additional attribute. Significantly, the skills and knowledge relevant to innovative potential are distributed across most of the graduate attributes, rather than being located in just one or two. This suggests that the way to focus attention on innovation in engineering programs is to position it as an integrative, meta-attribute.

Table 4. Emotional competencies inventories [16]

Cluster	Competencies
Self-awareness	Emotional self-awareness; accurate self-assessment; self-confidence
Self-management	Self-control; conscientiousness; adaptability; achievement orientation; initiative
Social awareness	Empathy; organizational awareness; service orientation
Social skills	Leadership; communication; influence; change catalyst; conflict management; building bonds; teamwork and collaboration; developing others

A significant risk associated with mapping the graduate attributes into individual courses and across whole programs is that of isolation and dilution. If a particular attribute, for example communications skills, is concentrated within a single course, it can become isolated rather than being seen as all-pervasive. On the other hand, if the various types of communication skills are totally disaggregated across many courses, there is a danger that it will get lost amongst the 'real' content of the courses. These risks are heightened for a meta-attribute such as innovation. Just because all the component skills and knowledge are covered somewhere in the program, this does not guarantee that students see the whole and more importantly are able to articulate it. Realizing that the whole is indeed more than the sum of the parts depends upon internal factors, including the innate attributes and orientation of the student to innovation. It can be shaped profoundly by external influences such as the lived culture of the particular school and the expectations that it promotes in the student body.

The graduate attribute paradox

There is what might be called the 'graduate attribute paradox'; developing graduates with those attributes stated by industry may not result in the types of engineers that industry requires.

Industry expects that graduates will have skills and knowledge such as those listed in the Table 3. Knowledge is acquired and, like skills, it can be demonstrated and observed. These are visible competencies. However, like an iceberg there are competencies hidden below the surface that are not directly visible. These include a person's social role or the image that they project to others, a person's self-image (their sense of identity and self-worth), their traits or the ways they are disposed to behave naturally and the core motives that drive their behaviour [14]. In selecting new employees, industry uses behaviour-based interviews and assessment centres which target the underlying traits, motivations, and values of the individual—their core competencies. Industry does this for the simple reason that these core competencies are a better predictor of the long-term performance of an individual in a particular industry context. Thus specific knowledge and skills, including non-technical skills such as communication skills, are seen by industry as a necessary but not sufficient condition in selecting engineers in terms of their likelihood of success in practice.

To demonstrate many of the attributes listed in Table 3 in practice, a graduate must have both the requisite levels of knowledge and skills *and* the appropriate motives, traits and other core competencies. However, much of the energy in teaching and learning in universities is now focused on developing the observable knowledge and skills dimension with little or no regard for the underlying, motivational competencies. So, while we might think we are developing the appropriate attributes in graduates, as articulated by industry, we may only be achieving part of the requirement.

Recently the American Society of Civil Engineers developed a 'Body of Knowledge' for the 21st century for engineers [15]. Significantly it contains not only a set of 15 knowledge and skill outcomes (an extension of the ABET criteria) but also a list of 'attitudes' that reflect a graduate's values, how they perceive the world and how they feel and behave in response to a situation. These attitudes include: commitment, confidence, consideration for others, curiosity, entrepreneurship, fairness, honesty, integrity, intuition, judgment, optimism, persistence, respect, self-esteem, sensitivity, thoughtfulness, thoroughness and tolerance. This raises numerous questions about whether or not attitudes can or should be taught and if and how they can be measured. Nevertheless, this integration of attributes and attitudes demonstrates the indivisibility of the observable knowledge and skills and the underlying motives and traits in achieving complete graduate outcomes.

As part of the targeted selection process commonly used in industry to select graduates, behaviour event interviews [14] seek to have the interviewee describe concrete instances in which they have demonstrated particular behaviours. This usually follows the STAR (situation, task, action, result) model: outline the situation in which the particular event took place, describe your role and responsibilities in this situation, describe what action you took to handle the situation and reflect on the outcomes that resulted. Performance in particular roles (technical, managerial) requires a corresponding profile of competencies.

The sorts of competencies that industry focuses on in employee selection fall under the rubric of emotional intelligence. This has been defined as that which is observed 'when a person demonstrates the competencies that constitute self-awareness, self-management, social awareness and social skills at appropriate times and ways in sufficient frequency to be effective in the situation' [16]. These four clusters each contain a number of competencies, as shown in Table 4.

Boyatzis et al. [16] observe that the behaviours related to innovation fall mainly into the initiative scale within the self-management cluster. By comparison of Table 4 with the innovation characteristics in Tables 1 and 2 and the description of Steiner [4], it is clear that competencies in all four clusters underpin or enable the behaviours expected of engineering innovators and entrepreneurs.

DISCUSSION

The significance of this cannot be underestimated in terms of the impact of the learning environment and the culture of an engineering school in achieving the goals of an engineering program as it relates to fostering potential innovators and entrepreneurs. Given that performance depends upon the individual, the task and the environment [13], developing innovative ability will depend upon the program (the skills and knowledge developed), the nature of the learning tasks and how they are constructed and assessed (the stated and tacit reward systems) and the school culture, including socialisation and any 'hidden' curriculum. It is a common experience that the *way we are* in an engineering school can have just as large an impact on outcomes as *what we teach*.

In those countries that have adopted outcomes-based curricula, there is considerable debate and discussion about how best to implement courses and programs which foster the acquisition of the stated graduate attributes. Effective and efficient methods of measuring outcomes are still being developed and refined. This is a considerable task. If we were also to consider identifying and measuring those attitudes that might influence the attainment of and the ability to use these skills and knowledge in a real engineering environment, we would face an impossible task.

However, if we recognize the influence of the attitudes and underlying traits of the individual on their ultimate ability to perform using the skills and applying the knowledge gained at university, we can compensate. This would require paying careful attention to how innovative the underlying learning environment really is and to fostering an innovative and reflexive school culture. Students should be informed about the attitudes that underpin innovation and entrepreneurship and their relationship with relevant skills and knowledge, as part of their personal development and self-awareness. The ASCE [15] observe that, if there is a lack of attention paid to attitudes in the teaching and learning efforts of universities, in concert with industry, then there is a danger that undesirable attitudes will be encouraged, to the detriment of all.

Beyond the individual graduate attributes and the underlying attitudes, there is the question of innovative ability. The behaviours that arise from the attitudes or underlying competencies of graduates can be characterized by a set of emotional competencies. There is a strong correlation between these emotional competencies and the traits of successful innovators. Equally, innovators require much of the knowledge and skills in the lists of graduate attributes. Thus innovation ability is a meta-competency that combines both the observable knowledge and skills in the graduate attributes with an appropriate set of deeper motives and traits. It is a meta-competency in its breadth and in its depth. It is not merely another set of knowledge or skills to be taught in addition to the regular curriculum.

CONCLUSION

Globally, engineering education systems are adopting lists of desirable attributes which engineers should be able to demonstrate upon graduation. These sets of graduate attributes contain both knowledge and skills and an implied set of attitudes or motives and traits for successful engineers. While engineering schools focus more on the knowledge and skills dimension of these attributes, long-term performance in practice is better indicated by the engineer's attitude. This leads to the graduate attributes paradox, whereby universities believe they are developing the graduate attributes that industry wants but industry remains disappointed because they are measuring different outcomes to those which the universities produce.

Moreover, innovative ability is a meta-competency that draws on both knowledge and skills contained in many of the lists of graduate attributes and a set of emotional competencies, underlying motives and traits. This has major implications for not only what is taught but also on the educational culture in which it is learned, especially in terms of nurturing the emotional competencies.

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