

# A Proposed Definition of the Engineering Methodology

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## BACKGROUND

An adequately concise and accurate definition of the profession of engineering that can simultaneously encompass a majority of the profession and be reasonably understood by a majority of society arguably remains as an elusive goal yet to be attained.

While numerous definitions of the profession exist they tend to describe specific methods or approaches deployed in the practice of engineering rather than be suitably descriptive of the profession of engineering.

The lack of an adequate, accurate and relevant definition of the profession of engineering has, and continues to, present disadvantages to the profession. While acknowledging this problem the profession continues to rely on existing inadequate, inaccurate, or irrelevant definitions of itself as it struggles to attain the degree of awareness, recognition, and appreciation of its significant benefits that directly impact society and the individual.

Accordingly in many countries the choice of engineering as a career path often ranks below other profession choices such as medicine, law, and management - especially with adolescent girls. Also the relevance and role of professional engineering in socio-economic and socio-political contexts is often undervalued or neglected – especially in national and international policy discussions and development.

## PURPOSE

To provide a clear, concise, and accurate definition of the profession of engineering that is acceptable for most, if not all, major stakeholders.

## METHOD

A review of historical and contemporary definitions of professional engineering is provided. Using Koen's definition of the engineering method in conjunction with Shulman's set of characteristics common to professions a more generic definition is derived that seeks to simultaneously accommodate the homogenous multi-disciplinary attributes of professional engineering as well as accommodate the discipline specific attributes.

## RESULTS

A proposed definition of the engineering methodology has been developed. A background introduction and justified derivation is provided for the proposed definition.

## CONCLUSIONS

The limitations and inadequacies of historical and contemporary definitions of professional engineering have been considered. Using Koen's definition as a basis a more generic multi-disciplinary and more contemporary definition is derived and presented. The goal of the proposed definition of the engineering methodology is to provide a more concise, more accurate, and most importantly a more comprehensible definition of the profession of engineering for the purpose of being applied to all major stakeholders of the profession.

## KEYWORDS

Engineering Methodology, System Model, Public Opinion, Heuristic, Engineering Method

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## Introduction

When we consider the professions of law and medicine there tends to be a reasonably intuitive understanding to most, including the general public, of what these professions contribute to society, what they involve, and the nature of work undertaken by individuals engaged in practicing them.

In 1992 the American Bar Association in the USA commissioned a survey of the public view of the legal profession (Hengstler, 1993). Responses from over 1200 participants nationally were collected by the survey: the participants selected to form a representative sample of the general population.

This survey found that nearly two-thirds of the participants had direct experience as clients for professional legal services during the previous ten years, three-quarters personally knew a lawyer, and half interacted with lawyers on a regular basis. Over half of the participants nominated as the most important role for a lawyers as “a protector of basic rights.” While only forty percent had favourable opinions about lawyers almost three quarters of participants had a definitive opinion about the profession: forty percent favourable, thirty four percent negative, twenty six percent neutral or unsure. For comparison the opinion of other professions was also surveyed across this sample with teachers being most favoured with an eighty four percent approval, and doctors favoured with a seventy one percent. Engineering profession was not included in the list of professions for which opinion was sought.

From this survey, putting aside the relatively low level of favourable opinion for the legal profession amongst the general public it is apparent that most people have a definite opinion about the profession, most had recent direct experience and interaction with the profession, and at least half identified the profession as upholders of justice and rights in society.

In 1999 the United Kingdom’s General Medical Council commissioned a survey of the public view of what constituted good medical practice (Peters, McManus, & Hutchinson, 2001). Responses from 1949 participants forming a representative sample across Great Britain were collected. The focus of this survey was to gauge the level of public dissatisfaction and complaint about the medical profession however one result is relevant: of the 1949 participants at least 85% had direct experience with a doctor in the previous year and over three quarters (79%) were satisfied with the professional services obtained, i.e., the doctor(s) had at least satisfied their expectations on what they would receive from a medical professional. While not definitive as a result, especially given the focus and structure of the survey, this does tend to indicate that a majority of the general public have a perception of the medical profession that aligns with how it is practised.

The high level of confidence in the medical profession was confirmed by Pescosolido et al (Pescosolido, Tuch, & Martin, 2001) who analysed survey data over a 20 year period for public opinion of the medical profession (and others) in the United States. While they did confirm an increase in the proportion of the public with a lack of confidence in the medical profession at the same time they confirmed that medical practitioners continue to enjoy a very high level of confidence with a decline due to multiple sociological trends and the public’s increased concern and dissatisfaction with healthcare industry trends.

The British Medical Journal inquired into the public perception of the medical profession in 2001 (Kmietovicz, 2002) and concluded that across the seven countries considered (including Australia) that about three quarters (74%) of the public held it in the highest regard. The Journal also concluded that the public’s understanding of the role of the medical practitioner has also evolved in recent decades – from that of a paternalistic repository and dispenser of medical diagnoses and cures to being more of a technician or gatekeeper to health services. Consistent with the evolution of the public’s perception and understanding of the medical profession is the majority opinion that the profession is dedicated to diagnosing, curing, and preventing health issues in society.

So if the public has confidence, trust, and a generally ubiquitous understanding of the professions of law and medicine what about the profession of engineering? A recent representative survey of the public involving over 2,000 participants in the United Kingdom (Ipsos MORI, 2014) revealed that over half of the public (52%) see no difference between science and engineering with science commonly associated with biology, chemistry, or physics. Almost one third (31%) believed they were not clever enough to understand engineering (versus 30% for science).

Disturbingly for the engineering profession, over a quarter (29%) of respondents in this survey believe that engineering is a dying industry (in the UK) as compared to less than half this number (13%) believing that science is a dying industry. On a positive note an overwhelming majority (90%) believe that scientists and engineers make a valuable contribution to society.

Although more than half the public see no difference between science and engineering there was some differentiating factors such as the need for creativity – almost half the participants (48%) believed that this was most important for engineers to be (compared to 28% for scientists).

And what about the public's perception of what professional engineers do? The survey revealed that while the proportion of the public who believe they understand what engineers do is increasing the proportion is only about three quarters (73%) with a significant number (15%) who do not know what engineers do. But does three quarters of the population understand what engineers *actually* do? Given that over half of the surveyed participants saw no difference between science and engineering it appears likely that the accuracy of public perception about the profession of engineering is significantly lower than three quarters, i.e., there (still) exists significant misconceptions about what professional engineering is and what engineers do.

The survey also revealed a consistent and salient artefact: those respondents who were either worked in science or engineering occupations or had regular interaction with science or engineering professionals responded with more confident and accurate beliefs about science and engineering. The corollary to this is that a significant proportion of the public do not regularly interact with science or engineering, or at least they believe they do not.

The Girl Scout Research Institute in the United States conducted a national study of the perceptions of a representative sample of over 850 teenage girls about STEM (science, technology, engineering, and mathematics) (Modi, Schoenberg, & Salmond, 2012). It found that two thirds of girls who are interested in STEM had a direct interaction with STEM fields and that over three quarters (79%) of girls who are not interested in STEM had more knowledge about non-STEM career options. It also found that almost three quarters (74%) of high school girls are interested in careers and study of STEM fields and professions. While the interest in considering a career in the engineering, physical/life sciences, maths, and IT fields was high (at 81%) the number of high school girls who selected one of these fields a first choice of career option was very low (at 13%).

Why is there a significant lack of understanding of engineering amongst the public? Is it due to the profession failing to promote and educate about itself effectively? Or is it due to the nature of the profession itself? Can engineering be as succinctly and accessibly defined for the masses as can other professions such as law and medicine?

## **Current Definitions of the Profession of Engineering**

What does the profession of engineering involve and what does a professional engineer do? When we consider professions such as law and medicine there exists for most people a reasonable and intuitive understanding of what these professions involve and what they contribute to society and to the individual.

While there is no universally agreed definition of what a 'profession' is or what a person who practices a particular profession (*a professional*) is there does exist a general understanding in society of what the terms "profession" and "professional" convey as descriptive terms. The Australian Competition and Consumer Commission (ACCC, 2011) has adopted a definition for '*profession*' from the Australian Council of Professions as:

*A disciplined group of individuals who adhere to high ethical standards and uphold themselves to, and are accepted by, the public as possessing special knowledge and skills in a widely recognised, organised body of learning derived from education and training at a high level, and who are prepared to exercise this knowledge and these skills in the interest of others.*

It follows that the various stakeholders in society have an interest in the quality and relevance of knowledge, skills, abilities, and behaviour of persons who practice a profession. Society expects persons who aspire to be, or are, practicing professionals to be sufficiently proficient with the knowledge, skills, abilities, and behaviour relevant to that particular profession: at least according to the public perception of the particular profession.

There exists an implicit agreement between society and a profession: in return for society placing its trust in a profession to self-organise and self-regulate the profession will deliver significant positive benefits to society. This has been considered in at least one definition of professions (Gardner & Shulman, 2005):

*Generically, professions consist of individuals who are given a certain amount of prestige and autonomy in return for performing for society a set of services in a disinterested way.*

This implies that there exists a reasonable public understanding of a profession and of how the profession is practised within society for any profession to maintain or improve its status and level of trust assigned to it.

All professions seek benefit from having society sufficiently understand the profession, such be entrusted to self-regulate, and it is reasonable to expect that the responsibility for developing and maintaining a sufficient level of understanding within society of any profession lies with the profession itself. This also leads to a corollary that in order for a profession to inform and educate society about itself it must beforehand have a sufficient understanding of itself. Furthermore a profession must have an understanding of itself that can be successfully communicated to others outside the profession.

There exists simple and widely understood definitions of law and medicine. But what about engineering? A common complaint from within the engineering profession is that society generally misunderstands it and worse, it generally has little knowledge of it and of the benefits it directly provides to society. Addressing the common nature of engineering and of engineering professionals to be less than directly visible to large sectors of the public in 1991 the chairman of Martin Marietta Corporation, Norman Augustine, referred to engineering as "the stealth profession, the silent occupation." (Braham, 1992).

Braham states that Augustine's criticisms of the public image of engineering incited the American Association of Engineering Societies to form a task force assigned to improve the image of engineering (Braham, 1992). In a survey involving 600 IEEE member participants in the United States an overwhelming majority (80%) believed that the public had no understanding of what an electrical engineer does (Wolff, 1993).

Sharp (Sharp, 2010) reports on a recent poll of chemical engineer members of IChemE about their beliefs on the public's perception (of chemical engineering). Over half (52%) of the poll respondents believed that the public perception of their profession had improved over the prior decade however this conflicted with individually expressed opinions from members such as an IChemE Fellow who stated, "Most people I talked to have very little or no idea what a chemical engineer does." Sharp also points to debate within the membership of IChemE as to whether chemical engineering is easier for the public to understand compared to the other major engineering disciplines. And this issue should be noted as it is

relevant to consider how well the profession understands itself (from inside) if we are to consider how the public understands it (from the outside).

In 2007 in the United Kingdom the Royal Academy of Engineering and the Engineering and Technology Board commissioned a national survey to assess the public perceptions of the profession (BRMB, 2007). One of the qualitative survey questions required the 1,000 representative public participants to try and identify which occupation (of the options to choose from; research scientist, education/teacher, medicine/doctor, or engineer) was best described by the statement, "It is an occupation where people are expected to come up with new ideas, face and overcome challenges and devise solutions to some of society's most pressing needs". Of the five choices, engineers came last with only a third of participants believing it described engineers. The majority (52%) believed it best matched research scientists. The more recent survey of public perceptions of science and engineering (Ipsos MORI, 2014) may help explain this earlier survey outcome via its finding there exists a significant public perception that there is no difference between science and engineering. This is supported by the 2007 survey (BRMB, 2007) where the most common belief amongst participants was that engineering related to building and construction activities and there existed a significant level of confusion by participants about the exact nature and role of engineering.

Few would argue that a clear and concise definition of engineering is needed. A definition that can be easily understood and be personally relevant to the majority of society (from outside the profession). But does a clear, concise, reasonably accurate, and most importantly an easily understandable definition of engineering even exist within the profession (from inside)?

The Millennium Project (James, 2008) settled on the following definitions of engineering and engineers as most compatible with those used by many professional engineering societies:

*Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize, economically, natural and man-made materials and the forces of nature for the benefit of humankind.*

*Engineers are persons who, by reason of their special knowledge and use of mathematical, physical, and engineering sciences and the principles and methods of engineering analysis and design, acquired by education and experience, are qualified to practice engineering.*

However the Millennium Project acknowledged the formality of these definitions and that other definitions may/could exist to better explain the profession and the practice of it.

Engineers Australia on its current website (Engineers Australia, 2014) is rather vague about what engineering as a profession encompasses when answering, "What is Engineering?". In answer to this question reference is made to "the huge variety of tasks and environments in which engineers find themselves," and that "a great deal of engineering work is done with the aid of computers". The webpage then goes on to provide definitions of specific engineering disciplines, in effect providing an "A to S of engineering disciplines" - from aerospace engineering to software engineering. Currently Engineers Australia eschews a generalist multidisciplinary definition of the profession instead preferring to be more definitive of the nature and role of engineering and of its practice within the context of specific disciplines.

An alternative approach is to seek to generically define engineering, as Schunn (Schunn, 2009) attempts with this definition:

*Engineering involves using analytical and empirical processes to design complex systems that meet stated objectives and take into account specific scientific and societal constraints.*

His explicit objective was to have a definition of engineering suitable for aiding the development of effective learning environments for children and whether by intention, or more likely incidentally, his definition is more descriptive of the methodology of engineering practice rather than of the profession itself and its direct impact to society.

Is Schunn's definition intuitive to a broad cross section of society? Recently UNESCO commissioned a report to examine the motivation and mechanisms for the transformation of engineering education. In the report (Beanland & Hadgraft, 2013) there is similar recognition that reform of engineering education requires clarity as to what the profession is and what the members of the profession do. They consider various definitions of engineering and adopt a broad definition of what professional engineers do from the OECD as:

*The work of professional engineers involves the application of advanced skills in analysis and knowledge of science, technology, management and social responsibility to problem solving, design and development in various fields.*

A survey in 2001-02 involving three hundred engineering academics and students in the United States (Sheppard, Colby, Macatangay, & Sullivan, 2007) sought an answer to the question, "What is Engineering Practice?" The answers provided by participants aligned with familiar concepts commonly expressed about engineering: that engineering involves problem solving and generating, evaluating and implementing solutions. However the survey failed to identify a common acceptable definition of engineering compatible with the variety of beliefs expressed by a majority of participants.

What about undergraduate engineering students in Australia? What is their level of understanding of engineering practice? What attracted them to choosing the profession of engineering as their career choice? A survey of over 1,540 final year students from 31 Australian universities in 2008 (DEEWR, 2008) revealed that 90% of participants nominated "enjoy problem solving, designing, creating" making it the most highly ranked motivation for enrolling in an undergraduate engineering degree course.

The Accreditation Board of Engineering and Technology (ABET) in the United States prior to the adoption of the Engineering Criteria 2000 (EC2000) accreditation standards in 1996 had commonly used a single-sentence definition of engineering (ABET, 1993):

*The profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind.*

Since the adoption of EC2000, ABET prefers to define general learning outcomes together with discipline-specific curriculum elements for the purposes of engineering course accreditation (ABET, 2013). This move away from attempting to provide a single multidisciplinary definition of engineering to providing discipline-specific definitions is consistent with Engineers Australia's current approach.

Numerous attempts have been made at providing all-inclusive definitions of engineering as a profession (that seek to include most of the major disciplines within it) and many tend to gravitate, in a similar way to examples presented here.

As such, definitions of the engineering profession tend towards being collections of attributes common to the profession or statements that attempt to weave elements of mathematics, science, and technology together with social responsibility and socially beneficial objectives.

Although engineering is readily recognised by most as a profession, alongside highly recognisable professions such as law and medicine, an easy-to-understand and easy-to-relate-to definition simultaneously acceptable by a majority of the profession (the insiders' perception) and a majority of the public (the outsiders' perception) remains elusive.

## **A Proposed Definition of the Engineering Methodology**

An alternative to seeking to provide a definition of the engineering profession is to alternatively seek to define a core element of the profession: the engineering method. The most notable of these definitions is by Koen (Koen, 1985) who defines the engineering method in the form of a heuristic that defines the use of heuristics:

*The engineering method is the use of heuristics to cause the best change in a poorly understood situation within the available resources.*

While Vaughn's heuristic for the engineering method offers relevance and identity a weakness of Koen's heuristic is that its accessibility for understanding is likely to be limited to those within the profession (the insiders) particularly since it requires an understanding of what a heuristic is.

In attempting to answer the question, "What is engineering practice?" (Sheppard et al., 2007) existing attempts (as existed at that time) to define engineering were examined and instead the authors chose to develop a model of engineering work to be applied within the contexts of engineering education. Their focus was to consider engineering as problem solving, as knowledge, and as the integration of process and knowledge. The root of their model was the set of six characteristics as defined by Shulman (Gardner & Shulman, 2005) that he considers are common to professions:

- *Commitment to serve in the interests of clients in particular and the welfare of society in general (i.e., an ethical commitment)*
- *Body of theory or special knowledge with its own principles of growth and reorganisation (i.e., a maintained body of knowledge)*
- *Specialised set of professional skills, practices, and performances unique to the profession (i.e., mastery of a domain of practice)*
- *Developed capacity to render judgements with integrity under conditions of both technical and ethical uncertainty (i.e., cope under conditions of uncertainty)*
- *An organised approach to learning from experience both individually and collectively and so growing new knowledge from the contexts of practice (i.e., continuing professional development and development of the profession)*
- *Development of a professional community responsible for the oversight and monitoring of quality in both practice and professional education (i.e., proactive professional community)*

Therefore considering Shulman's six characteristics of professions, by taking Koen's heuristic as a basis and redefining it to be relevant to the praxis of engineering, then it is possible to develop a proposal for a definition of the engineering methodology. In doing so it enables this praxis-oriented definition of the methodology of engineering to allow comparison of the engineering praxis against the praxis of other professions.

A proposal for a definition of the engineering methodology was developed by starting with Koen's heuristic and expanding the scope of it to include all methods employed in professional engineering practice.

Accordingly a proposed definition of the engineering methodology is:

*Engineering is a system of methods used to cause the best change in an environment of uncertainty and constraints.*

This definition aims to be understandable and acceptable to at least a majority of those within the profession (insiders) and is intended to be valid and applicable to at least all of the generally-considered major disciplines of engineering. Importantly it is intended to allow for the inclusion of methods used in engineering practice that are not from within the engineering profession itself or generally associated with engineering. For example, this definition's broad scope allows the inclusion of knowledge, skills, and abilities from other disciplines, vocations, bodies of knowledge, and from society in general.

As the proposed definition of the engineering methodology does not restrict engineering-related activities to the domain of professional engineers it is also inclusive of situations and circumstances where engineering, or engineering-related, work is performed by non-engineers.

A system model of this proposed engineering methodology definition is provided below.

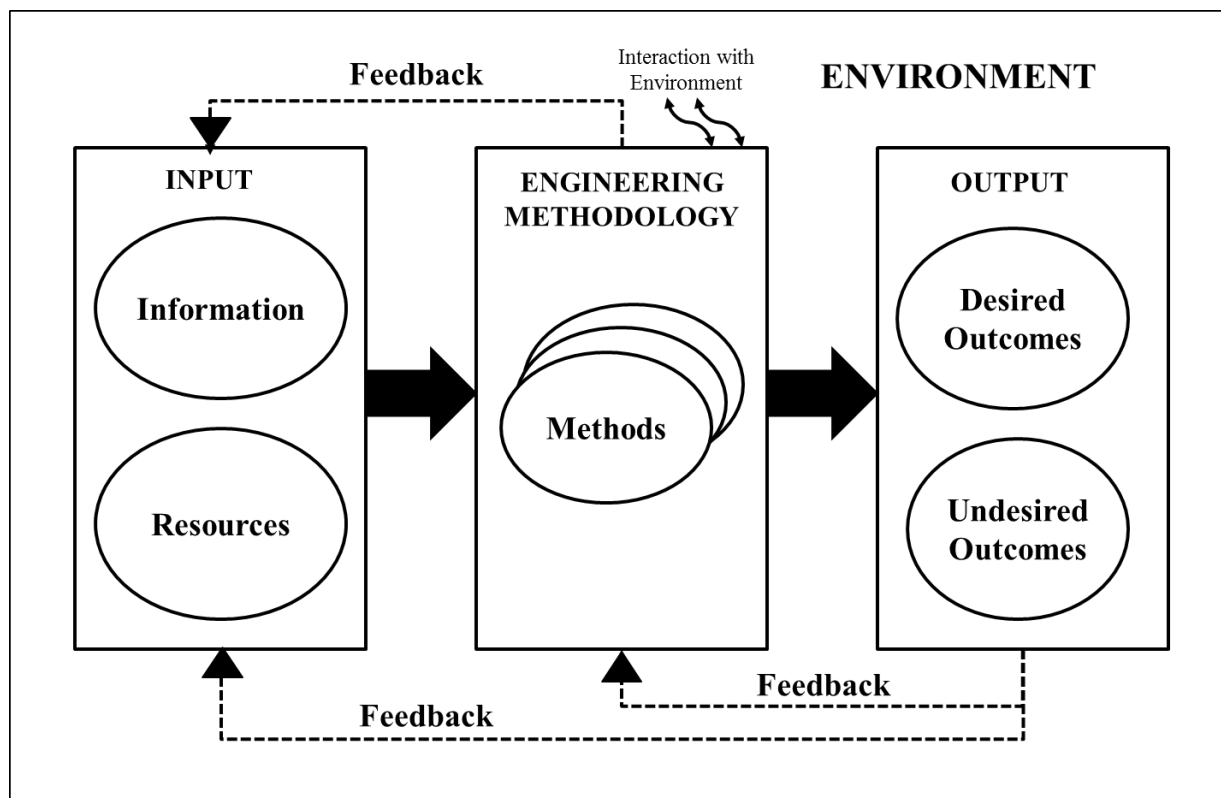


Figure 1: A System Model of the Engineering Methodology

This proposed definition of the engineering methodology does not seek to resolve the outstanding issue of providing a comprehensive, intuitive, all-encompassing definition of the profession of engineering to all stakeholders (insiders and outsiders). At a minimum it seeks to provide an accurate definition acceptable by stakeholders within the profession (insiders) as well as those who have direct interaction with the profession (informed outsiders).

It also seeks to provide a system model for engineering to assist with identifying and describing competency requirements for the profession and to assist with engineering education transformation efforts.

It is recognised that the proposed definition does not provide a universal and encompassing definition of *engineering* itself. Intentionally it fails to answer the fundamental question, “what is engineering?” And it fails since it was not the purpose of the definition to satisfactorily answer this question rather its purpose is to satisfactorily define the praxis of engineering.

A common complaint within the profession of engineering (the insiders’ perspective) is that it is little understood by the public (the outsiders). But if the profession from within struggles to agree on how to define itself then further efforts by the profession to enhance and elevate the status of professional engineering by informing and educating society about the nature and role of engineering are moot.

When seeking an answer to the question, “what is engineering?” and in particular when seeking an answer that is succinctly descriptive and embraces the entire engineering profession then perhaps it is appropriate to apply Ockham’s razor to this problem: if a suitable definition remains elusive despite numerous and varied efforts then perhaps the only feasible option is to accept that no single and universal definition of the profession of engineering is possible.



If the profession of engineering cannot be succinctly defined with universal and agreeable understanding by all stakeholders (inside and outside) then perhaps it should be accepted that the profession has existed, does exist, and will exist without such a definition. Rather than seeking a description of engineering via a definition it may be more appropriate to describe engineering as a paradigm.

By considering the profession of engineering as a paradigm a framework is possible where the entirety of the engineering profession simultaneously exists and is practised. A common problem with attempts at developing a “grand universal definition of engineering” has been, and continues to be, the emphasis in such definitions on how engineering is practised instead of what engineering produces. A focus on the processes rather than the impacts.

Revisiting the simple definitions of law and medicine discussed earlier, e.g., a medical professional is dedicated to diagnosing, curing, and preventing health issues in society. There is no mention in this definition of the knowledge or skills used by the medical profession. The definition is inclusive of the beneficial impact of the profession: diagnosis (identification), treatment, and prevention. The definition exclusively relies on stating the profession’s impact – measurable benefits provided to society.

This is similarly observable with the definition of the profession of law discussed earlier. Contrast and compare to a definition of engineering used by the US Department of Labor (Sheppard et al., 2007)

*... the application of ‘the theory and principles of science and mathematics to research and develop economical solutions to technical problems.*

Is a definition of engineering needed? Would it be acceptable to instead consider the paradigm, or paradigms, of engineering? An obvious motivation for seeking a universal and intuitive definitive statement of engineering is for its use in informing and educating society about the value of the profession and its professionals (Beanland & Hadgraft, 2013). But a problem with engineering is that it is a “horizontally diverse” profession inclusive of multiple disciplines such as civil, mechanical, aeronautical, marine, electrical, electronic, mining, and chemical. While many of these disciplines, especially those that are most prevalent (such as civil, mechanical, electrical, electronic) share common competency requirements and employ common methodologies this is not always the case.

The total production of the entire engineering profession is tremendously diverse (the output according to the system model of the engineering methodology) especially as it impacts and affects not only society at large but also as it directly impacts and affects the individual. This is being increasingly recognised globally as a key driver for transforming engineering education (Beanland & Hadgraft, 2013; Besterfield-Sacre, Cox, Borrego, Beddoes, & Zhu, 2014; Crosthwaite, 2014; National Science Board, 2014).

## Conclusions

The level of understanding within society of professions such as medicine and law owes, in large part, to the direct personal context for which individuals can relate to these professions. The profession of medicine can be considered in the context of a person’s health. The profession of law can be considered in the context of a person’s legal rights. The profession of engineering needs to present itself so it can be understood similarly by individuals within a personal context: to present a value proposition that is directly and personally relevant to the majority of society.

Aside from the increasing need for engineering to enhance its relationship with society, there are also other needs for the profession to understand itself: for example for the purposes of self-regulation, ongoing self-development, and in particular for the production and supply of competent novices (through effective engineering education) for the profession. For self-regulation and education there already exists formalised understandings of the paradigm of engineering – typically embodied in definitions of competency attributes, elements, and

indicators deemed necessary to be demonstrably exhibited by persons intending to, or currently, engaged in professional practice.

As an alternative to seeking a universally applicable definition of engineering instead a definition of the engineering methodology has been proposed. The proposed methodology definition may enable the development of more effective public information and education initiatives, recruiting initiatives, as well as assist in enabling the ongoing transformation of engineering education.

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