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The Status of Engineering in the Age of Technology: Part II. Principles of Practice*

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The social construction of technological action in the contemporary world demands of the engineering profession a fundamental commitment to pluralism. Long identified and characterised by an allegiance to instrumental problem-solving within a scientific worldview, the profession must now acknowledge and embrace equally legitimate and forceful ways of ordering our world based on the central principles of responsible choice in human affairs. The profession therefore faces a culture change in its educational foundations. This paper suggests that the growing emphasis on practice-based curricula is a proper and timely response to the educational dilemma facing the profession. It constructs a model of engineering practice to guide these developments, in which practice encompasses four core elements that issue from its essential pluralism. Practice, in turn, is seen as shaped and instructed by four corresponding, underpinning disciplines through an operationalising set of principles of practice. This principle-based model of practice, although expressed quite simply, offers clear directions for culture change in engineering education. It also presents a major challenge.

INTRODUCTION

SOLOMON [1], in an insightful analysis of the nature of engineering, identified pluralism as one of the central planks on which a philosophy of engineering should be constructed. To her, pluralism, philosophically a system of thought which recognises more than one ultimate principle, derives in the profession from the diversity of its roles and domains in society. She formulated a contextual framework which integrated four interdependent ways of understanding those roles and domains: the professional, the formative, the organisational and the cultural. In order, each is a context which 'encapsulates the traditions and realities of engineering as a profession . . . describes the engineering role and how it is enabled . . . reveals the positions of engineering in the world of work . . . includes the norms, values, myths and realities of the contemporary society and environment of which engineering is a part' [1]. These interpretative positions, as coincident constructions, each offer a valid way of looking at engineering. She argued that individually and together they insist on a fundamental commitment to pluralism, for each of them reveals different perceptions of what it means to practise engineering, and their connectedness exposes engineering as a rich tapestry of human qualities, beliefs and actions. This means that, in both practice and preparation for practice, the philosophical foundations of engineering must embrace a robust set of principles, transparently diverse yet patently congruent with its various roles and domains. The construction of a base of this nature represents a huge shift for engineering, for its traditional allegiance to instrumental problem-solving within a scientific worldview has nurtured a singular belief system. An unreserved commitment to pluralism demands that other, equally legitimate and forceful ways of ordering our world be now joined to this heritage to create a new vision of engineering wherein competing 'ultimate principles' harmonise. Alongside our attachment to and fondness for the long-established principles of constructing a tangible world through the efficient use of human and material resources, we must now add a deep and proficient concern for the ordered and political life of a community in which the central principles of intangible human affairs reign. Although a forbidding prospect, the profession must rise to the challenge and forge a humane and productive synergy between human needs and technological capacity and potential.

Accepting this immensely challenging responsibility creates a dilemma for engineering practice and education of proportions not encountered before in the long history of the profession. The last fifty or so years has certainly seen great changes as engineering set about moving from craft to science-based legitimacy, but the change needed for it to assume an influential role in the future technological society is of an entirely different order. In retrospect the scientification of engineering has been evolutionary, leaving many familiar cultural attributes intact. Now the profession faces revolutionary cultural change. The dilemma that confronts us arises in this way: the array of academic disciplines that underpin contemporary engineering education is already formidable; it is inconceivable that the equally

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formidable array of such disciplines concerned primarily with human qualities and social actions should be added on the same basis to that preparatory foundation. In fact there is wide acknowledgement that many engineering curricula are already overloaded with 'essential' basic science, mathematics (including computing) and engineering science to the effective exclusion of a secure grounding in praxis. The resolution of the dilemma obviously does not lie along that familiar but largely limiting path.

There is, however, a growing school of thought in engineering academe that the praxis often excluded by the sheer weight of disciplinary content ought in fact to be the primary focus of preparation for professional work. This is clearly the intention of Melsa [2] in his *Blueprint for the Future* for the College of Engineering at Iowa State University, for instance. His model of engineering education for the 21st century is built on three concepts: it will be learning-based, practice-orientated and demand active involvement of the student. In Australia, too, the 1996 Review of Engineering Education undertaken by the Institution of Engineers, the Academy of Technological Sciences and Engineering, and the Australian Council of Engineering Deans [3] recommended 'no less than a culture change in engineering education . . . to produce graduates to lead the engineering profession in its involvement with the great social, economic, environmental and cultural challenges of our time'. It noted that the present emphasis placed on engineering science has often acted to limit graduates' appreciation of the broader role of engineering professionals, and stated that greater attention must be given to the teaching of, and research into, engineering practice. Throughout the whole review document there is an insistent recognition that the reality of professional practice, in all its rich diversity, must be a major driver of the educational experience in engineering schools.

This paper, therefore, seeks to understand preparing for engineering practice in a way which might not only create space for those competing ultimate principles but also offer some signposts to a more outward-looking profession. The dilemma that we face, however, will only be set aside by the passage of the many, practitioners and educators alike, along new paths to an 'expanding responsibility' [3].

PRACTICE AND DISCIPLINE

Green [4], formerly of the School of Education, Syracuse University, relates practice and the academic disciplines that inform practice in a radical way. He is deeply concerned with the role of education in the acquisition of purpose in life, which he sees, in contrast to aimlessness, as representing 'confidence, hope, energy and the capacity to discriminate between what matters and what does not'. To him the acquisition of purpose is expressed in the formation, adoption, and pursuit of a worthy and workable life plan and characterised, in a person possessed of it, by at least five elements grouped in three categories: competence, discipline and practice, and service and the exercise of judgement. Competence and professional work clearly go together, for being competent means not only being good at doing something but also being good at doing things that some public values. A public in this sense confirms one's worth by responding to one's practice with approval. Furthermore, the public services most valued are those which demand both special expertise and a well-developed capacity for sound judgement in the midst of uncertainty. It is in the connection between discipline and practice, however, that Green's analysis offers insights particularly germane to preparation for professional engineering practice in the context of pluralism.

To Green, 'discipline . . . is the rule, order, form, or structure by which any practice is conducted'. It is essential to the acquisition of competence in that practice. Indeed, it defines that competence, for being good at any practice 'implies the acquisition and exercise of its corresponding disciplines . . . thus discipline is always connected to some practice'[4]. He puts forward the view, therefore, that the educational value of the academic disciplines does not lie in the mastery of their subject matter. To him the disciplines of the academy are not the various bodies of knowledge. They are the rules, order and structure stamped upon the conduct of human beings as they engage in the practice particular to the academy (that is, as they enquire); knowledge is the consequence of that practice.

Such disciplines certainly possess utility in practical affairs too, because they are revealed in the form they impose on our approach to the problems of ordinary life, but only as we address the need to know. Green says 'they will be present (then) as style is present in a work of art'. He makes a clear distinction, however, between the academic disciplines, which give form and structure to the exercise of theoretical reason, and the disciplines of 'ordinary life' which do so to the exercise of practical reason. The first is concerned with answering 'What can I know?', the second with 'What should I do?'. The practice of engineering in its pluralistic world, outside the academy, is fundamentally and always concerned with questions of both types. Technological action results mostly from the exercise of practical reason and is only partially informed by its academic disciplines. The disciplines of practice extend far beyond those of the academy. Indeed, given the social and commercial contexts in which the engineering practitioner must take decisions, it is these 'non-academic' disciplines that often occupy centre stage. It is necessary, therefore, that the foundation for education in engineering assembles certain disciplines, both academic and non-academic, in a

deliberate and purposeful relationship to the central elements of engineering practice.

Now Green takes the proposition that the competent exercise of any art or craft requires the acquisition of its corresponding disciplines a step further. To him, 'it requires their acquisition as *virtues* – that is, as the settled dispositions on which the standards, rules and structure of that art become stamped upon the conduct of the artisan' [4]. Given an essential pluralism in practice and education, the foundational disciplines of engineering might thus be seen to lead to a particular set of settled dispositions, or *principles of practice*, that guides the engineering professional in the exercise of the related practices. Sound engineering practice becomes, in this view, the responsible and competent exercise of its distinguishing disciplines according to certain principles of practice. The fundamental role of engineering education is then the exposition, development and preparatory exercise of these defining principles of practice. This is certainly not to suggest that specialised knowledge and high operating skill, the core of most contemporary educational programmes, are not central to good practice, for obviously they are. What it does open up, however, is the possibility that knowledge and skill might be best acquired against a meta-framework of principles. That framework must derive from both academic and non-academic disciplines, for the principles of practice can only be distilled from the exercise of all of its disciplines. They flow from purposeful engagement with real-world issues.

A MODEL FOR PRACTICE-BASED EDUCATION

Green's radical interpretation of the discipline–practice link (which in his work focused on the academic disciplines and the associated practice of enquiry) applied on a wider scale thus provides a compelling case for the adoption of practice-based curricula in engineering education. It may be that the growing move towards practice-based programmes is a heuristic response to the perceived failure of content-based pedagogy. Conceiving of engineering education as the submission to a defining and empowering set of principles of practice adds, I believe, an integrative core intention to that movement.

The internal structure of practice-based education that emerges from this is depicted in Fig. 1. In this model I suggest that there are four separate but contextually related elements of professional practice: governance, enquiry, management and design. Furthermore, these four, interpreted broadly, imply the acquisition and exercise of four corresponding groups of disciplines which I see as concerned to value, to know, to choose and to act. Discipline is then brought to practice through an operationalising set of principles which provide character and intent for the engineering approach. The model thus sees the philosophical basis of practice-based education as seeking to develop competence for practice through the purposeful and persistent application of certain operating principles founded on the defining disciplines of engineering.

Of course the formulation of a comprehensive set of principles to guide practice in engineering would be a task of heroic proportions, for it would aim to crystallise and encapsulate the wisdom of a great, enduring and diverse profession. Individual schools, however, might choose to construct a working model of principle-based education based on some few, clearly articulated, principles which encompass the wide range that issues from our essential pluralism. It is in this spirit that the discipline–principle–practice links are now expanded.

PRINCIPLES OF PRACTICE

Governance is used in this paper in a specific sense. The term itself is adopted from Vickers [5] who defined it as 'the art of imposing on human affairs, whether in the public or private sector, whatever kind and degree of order seems possible and desirable to those in seats of power'. He saw governance as a professional activity, despite the introduction into academe of disciplines purporting to ground the regulation of human systems in scientific enquiry, and that interpretation applies here. It is employed to describe an art or practice consciously aiming to promote and maintain certain forms of order in the human relationships which underscore all professional activity. It seeks the alignment of fundamental human needs, organisational goals and espoused values [5], and so must possess a moral dimension too, for not every kind and degree of order promotes worthy intentions. Governance here then is about the moral ordering of human affairs in the context of professional engineering work. The disciplines to be acquired and exercised in its conduct thus concern questions of life itself, and express the way a society values and strives to enrich the lives of its members. They are disciplines of ordinary life. The principles that bring effect to moral disciplines in the practice of governance, therefore, are those long-established in human affairs: respect for the individual, for the right to security, contentment, recognition and development of their potential. O'Brien [6], in an essay on character and the corporation, sees the possession of such principles as 'a predisposition towards helping another person to become complete'. He claims it is an interior predisposition towards our employees, customers, vendors, owners and other constituents that we can cultivate and direct by our will. He believes that the word 'love', at its most universal meaning, captures that essential predisposition and it seems to me that no word better expresses our

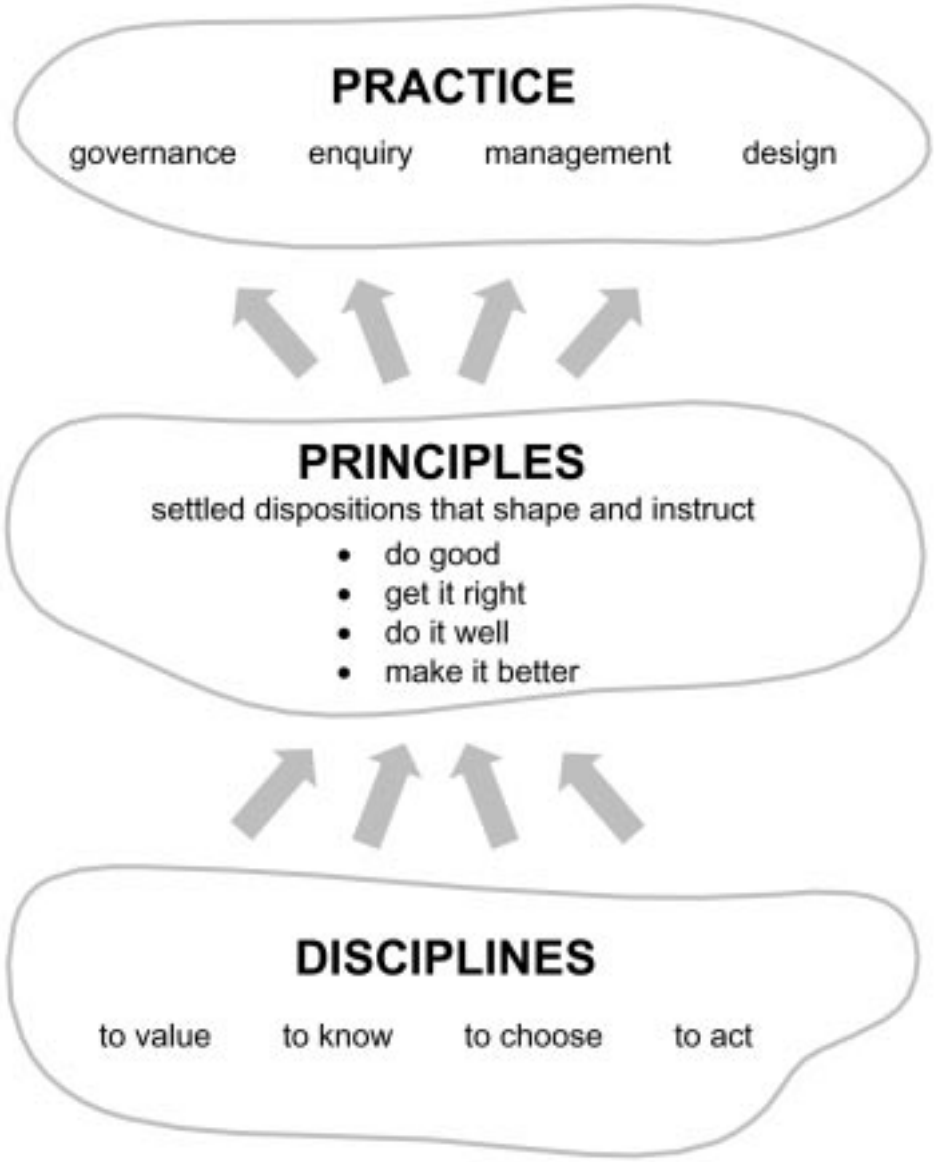

Fig. 1. An operational structure for practice-based education.

primary responsibilities as professionals. It is an unequivocable statement of principle in practice.

If the first practice–discipline path opens up a moral dimension for engineering that is not often explicitly recognised in its educational foundations, the enquiry-to-know connection is entirely familiar territory. Specialised knowledge has long been a defining characteristic of the profession. There is strong attachment to an intellectual tradition in which the facts speak for themselves, obviating the need to make a decision on uncertain grounds. In this element of practice, therefore, knowledge is held to displace the need for judgement. The knowledge bases that support such claims for objectivity are constructed through two distinct knowing disciplines, the empiricism of recording past 'good practice' and the application of the findings of science. Together these have an enormous influence on the way engineers attempt to interpret their world and stamp upon their conduct a special style. This style, treating the world in terms of knowable and manipulable systems, is that currently overwhelmingly displayed by engineering educators, is comfortably congruent with the mindset of most students and endures at least through the initial stages of employment. The principles that drive the practice of enquiry then are those of posivitist science, the gathering of all the facts, the search for theory to connect them, the quest for truth, and those established through past practice, the integration of the experiences and knowledge of others, the attention to detail, the caution with the new. They explicitly acknowledge the force of Richard Feynman's warning, given during the Challenger enquiry, that 'nature cannot be fooled'.

The disciplines that underpin the practice of management are also clearly of two types, both of and outside the academy. Management studies now have a strong presence in academe,

in economics, finance, business law and organisational behaviour, for example, yet much about this practice is considered to be an art or craft acquired only in service. The characteristic intent of management, however, remains the same whether its supporting disciplines at one time or other are mainly academic or of ordinary life, and that is the effective accomplishment of a specific task. Good management is about the responsible and productive use of all the resources available to the professional engineer, and so 'effective' here applies to the human, the commercial and the material domains. The essence of management is thus wise decision-making in these domains. The principles that translate the underlying deciding disciplines into practice might include clear strategy, open policy, merit-based objectives and decisions and commercial potential and propriety, and these, together with stable and stimulating leadership, create a culturally coherent work environment for good business.

The fourth discipline–practice link, to act by design, again opens on territory familiar and intriguing to the engineer. It is the promise of design, the creation of new and improved businesses, systems, structures, machines and artefacts in a technological world, that inspires and energises 'the limitless cleverness of engineers'. Its disciplines are decidedly both non-academic and academic, for a design outcome is at once new, and hence essentially untried, yet grounded in a hard-earned confidence that it will work. The new derives from the disciplines of ordinary life, or perhaps more accurately un-ordinary life, but the confidence in utility comes from a rigorous application of the engineer's academic disciplines. The principles that join such disparate foundations to its practice thus construct a necessary tension. Dissatisfaction with the commonplace, imagining what might be, and seeking new opportunities are tempered in implementation by rigorous analysis, evolutionary bounds and commercial perspicacity to ensure compliance with that demanding quality of engineering design, fitness for purpose.

The composition of the set of principles in Fig. 1 that serve to bring discipline to practice may now be sketched. In essence, I suggest, four core principles complete the four discipline–practice paths:

1. The practice of governance is shaped and instructed by the disciplines concerned *to value* through the principle *do good*.
2. The practice of enquiry is shaped and instructed by the disciplines concerned *to know* through the principle *get it right*.
3. The practice of management is shaped and instructed by the disciplines concerned *to choose* through the principle *do it well*.
4. The practice of design is shaped and instructed by the disciplines concerned *to act* through the principle *make it better*.

However, while each of these sharply reduced expressions of principle has been linked to a particular practice, principles really cannot be differentiated, for one may not take precedence over another. They must enter into the possession of the practitioner as a whole, and all must always guide practice. For this reason, then, while the model in Fig. 1 distinguishes discipline and corresponding practice, the principles which bring discipline to practice are depicted as forming a single set, coherent and congruent.

BEYOND PRACTICE

To imagine where this model of engineering practice as a guide to education might take us, it is worth quoting O'Brien again as he describes what it means to set up an 'enabled ecology' in a corporation, for what he says seems to me to be particularly apt for the set of principles of practice developed here:

> *These ideas are not new. Some, indeed, are very old. If they sound 'soft' to you, know that in actuality, they are hard work because they run against the grain of conventional practice; but . . . they pay dividends, for they release the potential stored in bound human energy [6].*

In that case, principle-based education and practice, by releasing human energy in a moral cause, clearly has ramifications for the practitioner far beyond competence in professional practice. It leads at its best to the development of character and self-worth for the individual and, in the service of a community ever more shaped by technological action, to an outward-looking profession seeking to act more determinedly with good judgement and wisdom, fitted indeed for its involvement with the great social, economic, environmental and cultural challenges of our time.

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