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On the Nature of Mechanical Engineering Work—Content and Process

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The machine was once a powerful metaphor for the enormous and obvious impact that mechanical engineers had on a burgeoning industrial society. Now the machine is ubiquitous, and perhaps so much taken for granted that the special role of the mechanical engineer is no longer apparent. Even within the profession, there appears to be no real sense of belonging to a distinctive discipline. This paper seeks to define an identity for the mechanical engineer by exploring the nature of mechanical engineering work. The paper begins with an analysis of content in mechanical engineering work from a broad brush educational viewpoint. It identifies the core subdisciplines on which day-to-day practice is built. It then turns to function, distinguishing the role of professional engineering from that of science, administration and politics. It shows that the nature of engineering work, too, is clearly different from that of other professionals. It describes engineering work in terms of process, identifying problem-solving, craftwork, networking and integrating as important elements of that process. It proposes a model of mechanical engineering work in which process operates on distinctive content to fulfil a special role. The paper argues that the absence of a clear vision of what mechanical engineering is, stems not from a change in its content over time, but from a failure to distil the essence of its practice, and from a lack of recognition of the singular role of the engineer-as-engineer. It suggests that the view of mechanical engineering work presented here has significant implications for both education and practice, offering a direction to revitalise our perception of the mechanical engineer.

INTRODUCTION

FLORMAN [1], in his *The Existential Pleasures of Engineering*, described the period 1850–1950 as good years for engineering, 'the Golden Age of Engineering'. It was a time when engineering emerged as a true profession. Great engineering schools were founded and flourished. Professional societies proliferated and, through increasing practice in the community, engineers 'grew in prestige, power, accomplishment, and self-satisfaction'. Engineers seem to have developed, in this period, a particular and positive view of their role in enhancing the quality of life of all people. Their special way of thinking offered a new vision of hope. The age-old human conditions of poverty and inequality were, at last, thought to be amenable to change through human intervention.

If this was true for engineers in general, it was specially true for the mechanical engineer. The enlightenment of the eighteenth century gave people a sense of possibility of change. it provided a social and intellectual framework that encouraged and rewarded technical ingenuity. The machine became the symbol of this possibility of change. In agriculture, the horse was replaced by a new farm 'workhorse', the steam-driven, and later, internal combustion-engined tractor. In industry, machines performed a multitude of jobs, the human worker becoming an operator rather than a source of power and dexterity. Rail locomotives opened the way to convenient mass travel over large distances, at high speed. Later, the automobile gave people a personal freedom of travel never before imagined. The machine also wrought fundamental changes in the nature of warfare, perhaps clearly evident for the first time in the 1861–5 American Civil War, but reaching horrific heights in the First and Second World Wars. Furthermore, during this momentous age, the machine, the powerful symbol of change, became associated with the individual engineer-designer and builder. Stephenson's Rocket, Whitney's cotton gin, Whitworth's standardised threads, Parson's steam turbine, Diesel's internal combustion engine, Rolls and Royce's aeroengines are only a few examples of this identification of the engineer with the machine. Much of the satisfaction of engineering seems to have come from this close association.

A second major theme which defined mechanical engineering, and its practitioners during this time, was the focus on the harnessing and control of natural energy sources in the service of industry. Industrial development, in turn, was seen as a powerful agent of social improvement. These energy sources were water, steam, coal, and oil, transformed into useful mechanical motion by machines. This harnessing and transformation of energy was physically obvious; machines had reciprocating rods, meshing gears and rotating

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flywheels. The repeatability, precision and rapidity of machines in accomplishing useful tasks created not only a sense of wonderment on behalf of those who beheld them but also a feeling of accessibility. The sheer power and potential of the machine, while frightening at first, led to a general acceptance of the machine as a metaphor for progress and regulation within an ordered society. It was the rhythm of the machine that came to dominate everyday life in industrial society. In this great social revolution the role of the mechanical engineer was self-evident; the engineer who created the machine was obviously central to the new society, for better or for worse.

In contemporary society things have changed. Rarely now are manufactured products linked to individual engineers. More likely a product will be associated with an impersonal corporation or a business logo. Likewise, no longer is the mechanical engineer seen to be central to the changes that continue to transform society. The fact that people use the term 'post-industrial society' is indicative of this shift in perception. Community perceptions are mirrored in the profession itself. Some mechanical engineers continue to see themselves through the symbolism of the machine age, yet the present day machines are so much a part of everyday life that overt recognition of that role is generally missing. Others see themselves as managers in a technological society, but the particular contribution that their initial formal education in mechanical engineering brings to that role is often not acknowledged and may even be denied. Still others have sought an identity in highly specialised areas, strongly linked to and often confused with scientific endeavour. In any case, mechanical engineers of today seem to lack a sense of collective belonging as mechanical engineers.

This lack of belonging is particularly apparent among university and college faculties charged with the education of professional mechanical engineers. While our experience as educators is mostly from an Australian perspective, we think that our own situation reflects and exemplifies more generally existing circumstances. Our experience, extending over more than thirty years, is that among academic staff there has been a steady and significant erosion of the idea that there is a central core of professional activity that really identifies mechanical engineers as such. As a consequence, students are exposed throughout their formal training to a multiplicity of intellectual and professional alignments or, perhaps even worse, to a flat denial that mechanical engineering, as a discipline in its own right, even exists. One colleague recently claimed that mechanical engineering was 'what's left after all the modern specialities had set out on their own'. This was expressed somewhat ironically, but it found a surprising agreement among others. This brings us to the focus of this paper. We believe that contemporary mechanical engineering education is seriously impoverished by the lack, among practitioners and teachers alike, of a clear understanding about, and general agreement on, what the profession of mechanical engineering contributes in this last decade of the twentieth century. There is an urgent need, in our view, to define the nature of that contribution and to make it explicit to provide a sound philosophical and epistemological base on which to build effective and stimulating educational programmes.

This paper aims to explore the special nature of mechanical engineering work. It concentrates first on content. Contemporary engineering covers an enormous range of interest areas, and it is difficult to single out the contribution that a particular branch of engineering makes in practice. We have therefore approached the issue of content from a broad educational viewpoint. The paper then moves on to process, setting up a typological framework for engineering activities in general. It places engineering work within that framework, drawing out and relating the different professional activities that daily occupy engineers. It then presents a model of mechanical engineering work by combining process and content to satisfy a role. It concludes with a discussion of the implications that such an interpretation has on the structure of mechanical engineering courses as preparation for professional practice.

CONTENT IN MECHANICAL ENGINEERING WORK

The following analysis is based on the premise that the issues which attract the attention and absorb the time of professional and mechanical engineers in their day-to-day work, will be reflected, in both philosophy and content, in teaching and research activities in engineering schools. The links are both formal and informal. The Institute of Engineers, for instance, exerts a direct and powerful influence on engineering courses in universities in Australia. Its members come from a wide spectrum of professional fields and so it can claim to represent professional practice in general. It seeks to maintain high standards of engineering work by placing certain requirements on entry to its membership. Educational institutions wishing to ensure that their graduates satisfy those requirements must agree to regular accreditation by special panels of the Institution. Accreditation requires certain entry standards, staff qualifications, subject areas and content, and opportunities for the professional development of students. Research, too, has strong ties with professional practice. Both private and government funding bodies tend to support those proposals which conform to current priorities, as established by perceived industry needs and government policy. The profession, through individual and collective submissions, has a significant say in the formulation of research policy. Individuals have a further input to direction when asked to referee funding proposals from university researchers.

In addition to these and other formal links, there is a good deal of informal interaction between industry and academe. Attendance at conferences, and service on committees of various professional representative bodies, offer important forums for discussion and debate. Visits to educational institutions by alumni are a good source of reflective evaluation. Student involvement in collaborative project work in industry provides another route for the interchange of ideas. Overall, there is a rich pattern of influence bearing on both staff and students and their interests at any one time will be largely conditioned by contemporary perceptions within the profession.

The pattern of influence is certainly apparent to us in the Department of Mechanical Engineering at the University of Queensland. The department itself is fairly typical of mechanical engineering schools in Australia. There are approximately 300 undergraduate students overall in the second, third and final years of the course (the first year is common to all engineering disciplines and comes under the aegis of the Faculty) and about fifty Master's and Ph.D. candidates in the graduate school. An academic staff of fifteen is supported by thirty clerical and technical staff. Academic staff tend to teach and research in their own specialities and have responsibility for course content and approach in subjects within those specialities. While we have suggested that the approaches adopted in all courses will be subject to a general influence from mechanical engineering practice, there is one particular course where this influence appears to be most evident; the final year individual thesis.

The thesis is considered to be a particularly important part of the university experience. For Honours candidates it represents some 30 per cent of the final year's work and, for Pass students, about 16 per cent. It is project-type work, taken individually under the supervision of staff members. It is seen as an opportunity to put into practice what has been learnt throughout the degree course, and to develop strong professional competencies. However, of interest to us here is the choice of topic for the thesis. There are two sources: most students select their topic from a list prepared by the staff, which contains titles which directly reflect the research and scholastic interests of the faculty, while a few students propose their own topic, in areas of personal interest or arising from vacation work in indusrtry. The latter must then find a member of staff who is willing to supervise the work. In either case, we believe that the topics finally selected will be a good indicator of current academic and professional concern. An analysis of the subject areas covered by thesis topics should therefore provide a useful guide to what practitioners consider to be the proper focus of mechanical engineering, that is, to the content of mechanical engineering work.

In the period 1930–89, 919 undergraduate theses were undertaken in the department. Our analysis of the titles, backed up by a long and close association with the department which enabled us to identify most theses with particular staff members, past and present, showed that theses could be categorised under a small number of subdisciplines, namely design, dynamics, fluid mechanics, manufacturing, solid mechanics and thermodynamics. The specific focus or application of the theses within these generic areas has changed over time. For example, there was considerable emphasis on turbomachinery in the area of fluids in the early years, which gave way to flow in air-cushion vehicles and supersonics (1960s), then to turbulence (1970s), and more recently to hypersonics. Nevertheless, the fundamental attachment to fluid flow has remained. A similar evolution of interests occurred in manufacturing, where an early preoccupation with metrology changed to operations research and then, in parallel, to computer-aided manufacture. Again, the basic concern with operations that make things, has been remarkably consistent over the years. The same pattern of development is exhibited in the other streams but they too maintained a consistent presence. It is clear that there is a core content that attracts the attention of mechanical engineers, that they see as defining their special place in the engineering lexicon. That core is made up of design, dynamics, fluids, manufacturing, solids, and thermodynamics.

There have been some changes over time in the relative proportions of these core subdisciplines. Table 1 shows the percentage of theses in the various subdisciplines, averaged over decades, from 1930 to 1989. Theses taken in 1990 and 1991 follow the same pattern but have not been included. The small number of theses undertaken in the department up to 1949 means that the first

Table 1. Theses topics in mechanical engineering, University of Queensland 1930–1989 (per cent in subdiscipline)

	1930–39	40–49	50–59	60–69	70–79	80–89
Total	20	38	85	165	263	348
Design	5	15	7	6	8	18
Dynamics	10	4	15	20	26	24
Fluids	27	8	20	14	20	21
Manufacturing	20	30	18	24	16	12
Solids	5	13	6	16	15	10
Thermodynamics	33	30	34	20	15	15

two columns probably should be considered of historical interest only. From 1950 onwards, the most notable change has been the drop in the percentage for thermodynamics. Fluids shows a small increase from 1960 onwards, while dynamics shows an increase from 1950. Manufacturing has decreased somewhat from 1960, as has solids. However, overall there have not been any drastic changes or deletions. It seems that the habits of mechanical engineers have stood the test of time. There have been, however, some relatively recent additions to the tools available in the various subdisciplines. Modelling, simulation and software development, obviously associated with the introduction of the computer, have expanded from 1960 onwards. The development of computer-aided design and drawing packages, for example, gave rise to the increased percentage for design in the decade 1980–89. Computer simulation in dynamics has also attracted a good deal of attention. However, these tools have not led to the formation of new subdisciplines. Mainstream engineers have adopted the new tools and techniques where appropriate, and work in these areas has expanded as a result, but no new directions have become evident.

This broad analysis demonstrates that there has been a remarkable resilience in the things that occupy mechanical engineers. There is a strong heritage in which contemporary mechanical engineering is grounded. The content of mechanical engineering work is distinctive and robust. We now turn to consider mechanical engineering process. In the following analysis, which begins with a discussion of the function of engineering, we have considered engineering in general rather than suggest that mechanical engineering follows a process distinct from other branches.

THE FUNCTION OF ENGINEERING

In industrialised society the majority of mechanical engineers, and indeed of most engineers, work in, or for, technologically-based institutions, whether government agencies or private industries. According to Price [2] such institutions are typically large-scale and have to be organised in a special way 'in order to translate abstract scientific knowledge into purposeful action.' Price discerned four broad functions in government and public affairs—the scientific, the professional, the administrative and the political. He argued that the existence of these four 'estates' seems to be common to all countries with advanced science and technology. In the western tradition the separate contributions that each of these estates makes to the working of a technological institution, can be explained by locating them along a spectrum from power to truth. The political estate resides at the power end of the spectrum, next comes the administrative, then the professional and finally the scientific, at the truth end. In the categorisation of human activities in institutions, while every person may be concerned to some extent with all four functions or estates, each will generally tend to associate his or herself with one or another. The functioning of the institution depends on how the four types co-operate or conflict with one another.

The ways of thinking of, and matters of consequence to, these groups are quite different. The scientific estate, according to Price, is mainly interested in material phenomena and their causes and effects, studied ideally without concern for purposes and values. The professional estate, in contrast, is primarily directed at putting ideas into practice, a role in which purposes, values and standards must be central considerations. The administrative estate provides the focus for technological and scientific activities, to ensure that the flow of ideas, information and power within the organisation generates and maintains an informed and workable policy. The political estate concentrates on the formulation of policy and the resolution of conflicting demands and needs. Engineering clearly belongs to the professional estate as it has a role in public affairs that is different from the role of scientists on the one hand, and from the roles of administrators and politicians on the other. That special role is the purposeful application of scientific and other systematic knowledge to practical affairs and it is fulfilled by a profession organised, according to Price, 'around a combination of social purpose and a body of knowledge.'

It is useful to expand on the function of engineering at this general level because it not only serves to distinguish engineering from other occupations but also illuminates the essential and unique contribution it makes to society. Since the profession deals in practical affairs, two things about its nature become apparent. First, it cannot purge itself of concerns of values and purposes, as Price suggests science aims to do, rather, such concerns are central to its function. Engineering work is thus about compromises, of satisfying the often conflicting or competing demands that characterise social purpose. Secondly, and somewhat paradoxically, it cannot base its concrete and practical constructions on political directives, on which members of the administrative estate might be obliged to formulate their actions, since the engineer must build structures and systems that will work. The profession therefore seeks to ensure the quality of its work with an almost corporate organisation with controls over admission standards, a responsibility to serve within a defined and limited field, and an obligation to standards of ethics and competence set by the profession itself, not by employer or client. So engineering work is unique; it builds on systematic knowledge, much of it now deriving from the sciences, yet it applies that knowledge to the satisfaction of personal and social purposes expressed in terms of power. It is a bridge between the sciences and politics. It is not a derivative of scientific enquiry, indeed many of the great engineering works of the past owe little to scientific knowledge. Neither is it the operational arm of management, serving only to give a practical effect to concepts arising from political wishes. It occupies an important place of its own in the field of human endeavour.

THE CONTRIBUTION OF ENGINEERING

The location of four estates, the scientific, professional (with our focus on engineering), administrative and political, along a spectrum from truth to power gives important insights into the different, but complementary functions of the various occupations. In this section we aim to further elucidate the professional engineering contribution by locating the estates along two more dimensions. The approach parallels that used by Burrell and Morgan [3] in their analysis of the sociology of organisations. These authors developed a typological map based on two orthogonal dimensions, one describing a spectrum representing assumptions about the nature of science and the other a spectrum representing assmptions about the nature of society. Thus one (horizontal) dimension went from a subjective interpretation of science to an objective one, while the second (vertical) one went from radical change to regulation. Burrell and Morgan found that placing different approaches in sociology on the map made it possible for a coherent scheme for the analysis of social theory. We suggest that a similar construction may be used to further explore the nature of engineering work.

Figure 1 shows our interpretation of where engineering lies relative to the other estates on a map formed on two axes, one representing ways of knowing (subjective–objective) and the other representing attitudes towards prevailing social mores (critical–accepting). The areas occupied by the various estates are meant to indicate the numbers of people engaged in the different functions in technologically-based organisations, excluding support staff employed in technical or clerical roles. We suggest that the professional group is normally larger than those concerned with scientific studies. The administrative group is smaller than the scientific, while the political estate contains the least numbers. The estates are shown overlapping to some extent, suggesting that the different roles merge into one another. Nevertheless, the construction does indicate that the centroids of the area, the loci of regular attention for people performing the different functions, are quite separate on this typological representation.

Science, concerned as it is with abstract truths about material phenomenon, we place in the second quadrant, described as generally accepting of the way society is currently organised and primarily seeking objective knowledge. Admini-

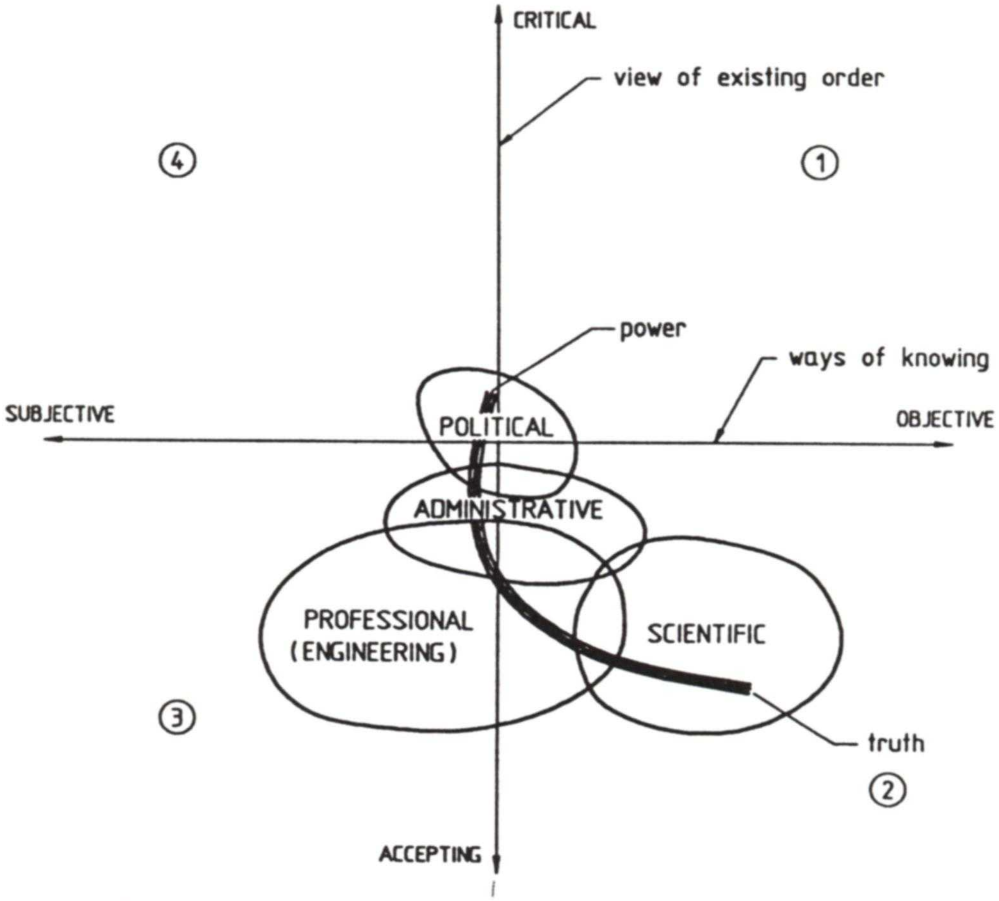

Fig. 1. A typological map of functions in technologically-based organisations.

stration deals much more with organisational culture and personal experience of the world, but is still essentially non-revolutionary, occupied with implementing political directions to maintain stability. Administration may also embrace scientific management principles. We therefore locate this estate mainly in the upper corners of the second and third quadrants. The political estate fulfils a dual role, sometimes critical and revolutionary, while seeking to maintain existing power relations. It is shown occupying space in all four quadrants. Engineering in this framework spreads across two quadrants, being much concerned with objective ways of knowing, and therefore closely linked with scientific knowledge, but also necessarily responsive to social and personal purposes in which subjective ways of knowing predominate. Again engineering work, like science, is basically accepting of its social milieu. This is not to say that engineering and other technological activities have not revolutionised the society we live in over the past 150 years or so, but rarely do individual engineers purposefully go beyond the sure and tested boundaries of their knowledge. Engineering, therefore, is located in the lower half of the map across the second and third quadrants, overlapping science at one extremity, linked to administration but not directly connected to policy determination. To tie this representation in with the general nature of engineering work, the power to truth spectrum appears as a curved line in Fig. 1, reaching from power in the fourth quadrant through the administrative and engineering estates to truth in the second quadrant.

Our purpose in choosing subjective–objective and critical–accepting spectrums as dimensions perhaps now becomes clearer. Not only is the function of engineering distinct from the others, as indicated by its position along the power to truth spectrum, but also it must be accepted from Fig. 1 that engineering work, the pathways that practitioners take while putting ideas into practice, will be quite different to work in the other estates. This is an important conclusion because in our experience, as we have noted earlier, there is a good deal of confusion about engineering practice enjoined by models of the engineer-as-manager, or the engineer-as-scientist. Here we claim a singular role for the engineer-as-engineer, operating through *process*, that draws on both subjective and objective knowledge that is grounded on established and tested ways of doing things but which, ultimately, leads to products and systems that satisfy the dynamic material demands of the community. The elements of that distinctive process, and the relationships between them, can now be more fully grasped.

ENGINEERING AS PROCESS

Turning now to the sorts of activities carried out within the engineering estate, we distinguish four different types of work, namely problem-solving, craftwork, networking and integrating, which together enable that constructive use of knowledge which characterises the engineering function.

Problem solving

Problem-solving has long been recognised as a central and important activity in both engineering and scientific endeavour, and many engineers like to think of themselves as problem-solvers. Page and Murthy [4], for example, claimed that engineers are essentially problem-solvers. It is a way of thinking with deep roots in western scientific traditions. It has been closely identified with engineering, particularly since the 1950s when 'hard' systems-thinking began to gain influence. Problem-solving involves, in order, problem definitions, selection of appropriate analytical tools or mathematical models, the generation of solutions and the evaluation of those solutions against set objectives to optimise the outcome. It is recognised, among designers at least, that these steps may be revisited via feedback loops. The process is aimed at a systematic exploration of the problem 'space' by abstracted analysis and is thus attractive to engineering educators. Many courses aim at developing problem-solving skills in particular subdisciplinary areas. Not unexpectedly, the subject matter of such courses is restricted to mathematically tractable examples dealing as far as possible with objective knowledge, rather than with the subjective aspects of engineering work. By training then, and perhaps by predilection also, engineers tend to be comfortable with their problem-solving role. In Fig. 2, wherein the focus is on the engineering estate, problem-solving must be located at the right-hand end, mostly in the second quadrant, clearly identifying with scientific, objective ways of thinking and a ready acceptance of existing order. Its chief characteristics are rationality, objectivity and freedom from personal values.

Craftwork

Engineering work is essentially evolutionary. Day-to-day practice is grounded on accepted ways of doing things. These may be enshrined in professional codes of practice, or in company or institutional guidelines. Craftwork skills are about becoming aware of such ways, and learning when and where to apply them. Such skills are not generally taught to a significant extent in academe, rather, they are learnt on the job and are counted as experience. 'Know-how' is a generic term often used to describe craft skills. Knowing how seems to be quite different from problem-solving. It involves understanding how things may be done in their special context. It is not abstracted analysis. Craft skills are gained from cumulative experience under practical conditions and often incorporate subjective judgement and intuitive feelings about particular circumstances. On the job learning leads to that ill-defined, but nevertheless real, quality of developing a 'feel' for the situation which seems to rely

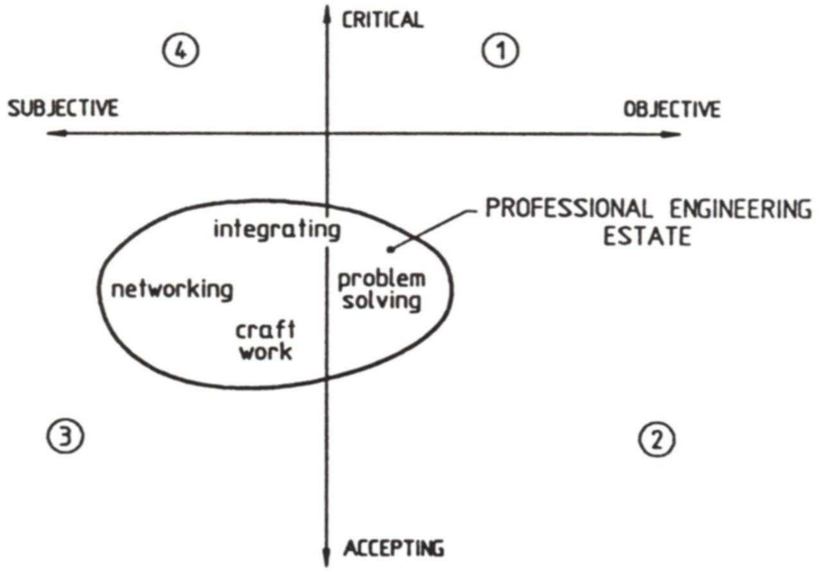

Fig. 2. Types of work located in the engineering estate.

on a wide range of inputs. Through craft competence, a professional inspires confidence in his or her decision or advice. Professional maturity seems to be derived from the acquisition of craft skills.

The contextual quality of craftwork means that much activity is based on a subjective assessment of what is applicable in a certain organisational and social setting. It should be located in the third, subjective quadrant although its spread would include elements of objective knowledge as required. Although judgements are employed in selecting relevant craft knowledge and skills, such judgements are made within the existing framework of accepted values. Its characteristics are experience, cultural acclimatisation and technical judgement.

Networking

Engineering has never been a solitary occupation. It may still be possible for a scientist to work in splendid isolation, bent on unravelling some further mysteries in the natural world, but generating a practical, material outcome to an idea of social consequence, demands support and contributions from many different people and organisations. While engineering work must be based on sound theory and good practice, it is conceived and implemented by a broadly-based network of human actors, each bringing to it different perceptions, skills and expectations. These actors, or stakeholders, will have different goals, experiences and methods so that competition and conflict in human relationships are as likely as co-operation and collaboration. An essential attribute of the engineer is to be able to create, maintain or avoid certain forms of relationships, that is, to be able to network within a social milieu. Networking is about 'knowing who' and 'knowing where', about whom to talk to, and where to find them, to further a plan for putting an idea into practice. Like 'knowing how', 'knowing who and where' takes time and effort to learn and perhaps cannot be taught to any appreciable extent in formal courses. Nevertheless, the skilled practitioner in engineering who has built up an effective and responsive network of personal contacts, possesses recognisable qualities. Since developing the necessary contacts involves largely subjective judgements about influence, power, helpfulness and support, networking is clearly located in the left-hand region of the engineering estate. In our view, it must occupy a significant proportion of the total estate. Its primary characteristics are familiarity with, and sensitivity to, the web of human relationships that creates the social fabric of engineering.

Integrating

The fourth type of engineering work we wish to distinguish may be defined as the creation of new order. The urge to create and embody something new of utility or, perhaps less recognised as equally imaginative and innovative, to marshall the skills, energies and resources of others in the advancement of technological purpose, lies at the very heart of the immense impact that engineering makes in contemporary society. The creation of new order with both form and purpose, demands a special kind of thinking. First, it requires the capacity to imagine what might be, to appreciate within a given situation the opportunities that may be grasped. Secondly, it requires the conceptual ability to formulate a plan to realise those opportunities, a plan that recognises and draws together the necessary and sufficient separate elements, human and material, within a cohesive and purposeful whole. The plan must then be put into action so that the original ideas are given practical effect.

At one level, this creative process has long been acknowledged as a central plank in engineering education. Courses in engineering design aim to give would-be engineers experience in synthesis, to complement, and to set in context, the development of analytical skills. However, machine or mechanical systems design is but one expression of the creative urge and discipline by which new artefacts, products and systems of utility to society, are envisaged and realised. This sort of work appears to be quite different from problem-solving, craftwork and networking. It involves imagining, originating and synthesising, and is triggered by a desire for novelty, or a dissatisfaction with the way things are done. It should then be located in the upper regions of the engineering estate in Fig. 2, encompassing both subjective and objective ways of knowing.

What emerges from this analysis is that not only is engineering work distinctive, quite different from administration and science, but also it is immensely rich in complexity. If we now join this rich process to the special content of mechanical engineering, the singular nature of mechanical engineering work can be defined.

A MODEL OF MECHANICAL ENGINEERING WORK

An Organization for Economic Co-operation and Development (OECD) study had this to say about engineers;

> most engineers are trained, and spend their lives, in the application of existing knowledge and techniques to the specification, design, procurement, installation, commissioning and maintenance of variations upon the vast range of established processes and products. In this way they play a crucial role in enabling the processes of production, construction and indeed most economic activities to function efficiently and to improve [5].

The role of the mechanical engineer, picking up on this idea of enablement, can be defined then as enabling the processes of production and construction through the application of the subdisciplines of design, dynamics, fluids, manufacturing, solids and thermodynamics. The content of the profession, its underlying knowledge is not a disembodied group of facts and equations, but rather a particular set of shared understandings of nature and technology. Working through the processes of problem-solving, craftwork, networking and integration, the mechanical engineer, as a member of a team, assumes the authority to act on behalf of an employer, in the production or construction and distribution of artefacts with specific utility. This process draws deeply on the history and developments in the six subdisciplines. This combination defines the unique contribution of the mechanical engineer. Figure 3 shows how this may be represented, process operating on content, to fulfil a special role.

The model claims that mechanical engineering is a purposeful activity which leads to the satisfaction of a broad range of material needs in contemporary society. It is a model of the engineer-as-engineer, operating through a distinctive process on specialised knowledge, to translate ideas into practical purpose. It acknowledges and even celebrates the particular function of the engineer within the professional estate. By getting beyond the narrow view of a mechanical engineer as essentially a technical functionary in the service of a limited managerial or even political end, this model highlights the rich social dimensions of the profession. This shift of primary focus from content to process, from a technocentric to an anthropocentric view, fundamentally changes our perception of the mechanical engineer.

This view of mechanical engineering work has significant implications for professional education. Traditionally, mechanical engineering education has focused on building a strong knowledge-base from mathematical and scientific ingredients, cemented together perhaps with practice of problem-solving in selected, tractable examples. In general, considerations of process have been limited to descriptions of, and some practice in, engineering methods in design tasks. This model, however, suggests that much greater attention needs to be paid to process, which in turn may lead to a necessary broadening of the traditional knowledge-base approach for objective problem-solving to incorporate craftwork, networking and integrating.

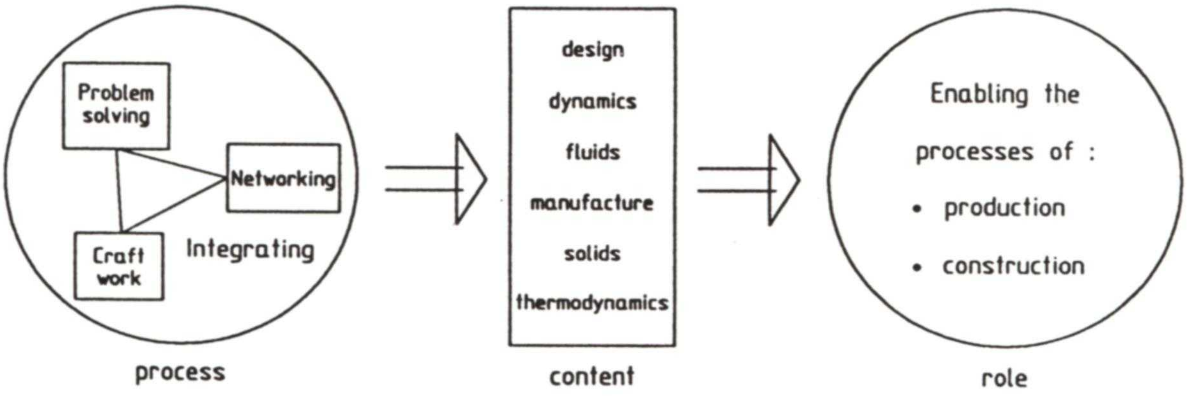

Fig. 3. A model of mechanical engineering work.

The view of the profession depicted in the model also opens up new domains for scholarly enquiry into the processes underlying mechanical engineering. Such investigations would go beyond current studies in engineering management. They would involve the fusion of ideas and techniques from diverse disciplines such as anthropology, sociology, history and engineering to create new means for reflection and for self-awareness by the engineering profession. The resultant methods would be part of the profession, not external to it. A small number of such fusions have recently appeared in the engineering design literature, for example, the use of ethnographic methods by groups of engineers, architects and anthropologists to explore engineering design as a social activity [6, 7]. A shift in this direction will counter the current dominance of the mechanical engineering sciences as the accepted form of enquiry for investigating the domain of mechanical engineering and it will help to restore the balance on our perceptions of the work of the mechanical engineer.

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