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On the Nature of Mechanical Engineering Work—Generic Professional Competencies*

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The aim of this paper is to uncover and describe the competencies demanded of professional mechanical engineers in their work throughout a career in engineering. It begins with a review of some insightful interpretations of the special qualities required of professionals in general, particularly the work of Vickers, Schein and Schon. It draws together the themes which emerge from these analyses and proposes that five distinct but closely interrelated generic competencies provide the basis for effective accomplishments in engineering practice. The competencies that form this set are special knowledge, operating skill, sense-making ability, sound judgment and wise direction. The paper then traces the acquisition and development of these competencies throughout an engineering career defined by three broad stages. It argues that full professional capacity is reached only after time in practice, through the progressive introduction and expansion of the separate competencies. A model of competency development is constructed which suggests that as each competency is added through engagement in practice, the ones which have been exercised earlier acquire a more secure basis. In the light of this reasoning, the paper concludes that mechanical engineering education needs to promote a culture which values professional practice and to adopt a philosophic base which is appropriate to engineering, not science.

INTRODUCTION

IN the halcyon days of the American space effort during the 1960s engineers noted wryly that if a space shot was a success the media called it a scientific triumph; if the mission failed or had to be aborted it was reported as an engineering failure. While this somewhat apocryphal interpretation of media coverage was no doubt due to the heavy pressures to succeed felt by engineers working in the industry at that time, it did reveal a concern that the real contribution that engineering made to such ventures was poorly understood. It appears that little has changed in the past 30 years in this regard. The contribution that engineering makes in an increasingly technology-driven society is still not widely understood. And yet the intelligent use of our technological capabilities is crucial to the well-being of contemporary society and indeed to that of future ones. It is high time therefore that the role of the engineer in society be made much more transparent, so that both the opportunities for enhanced quality of life and the dangers of unwise developments that flow from that role are recognized.

In the first paper in this series on mechanical engineering in particular [1], it was noted that even amongst professional engineers, practitioners and educators alike, there is widespread confusion and disagreement about what it is that mechanical engineering really contributes to contemporary society. It seems that while engineers in industry appear to have no difficulty in relating to the idea of the 'engineer as manager' in a technological society and engineers in academe may relate to the 'engineer as scientist' in a research environment, there does not appear to be a clear conception of the special role of the 'engineer as engineer'. It was argued in that paper that engineering does indeed have a unique and important place in the field of human endeavour, forming a bridge between political aims and systematic knowledge, as it satisfies the dynamic material demands of the community. Mechanical engineering, with its concern for the many processes of production and construction that promote and sustain economic activity, draws on a particular set of core technologies in fulfilling that role. The paper identified six of these, namely design, dynamics, fluids, manufacturing, solids and thermodynamics. It was proposed furthermore that the mechanical engineer employs these technologies within a distinctive engineering process, in which problem solving, craft work, networking and integrating are important elements. A process–content–role model was then constructed to describe the enabling capacity by which ideas are put to practical effect by engineers.

The second paper on the nature of mechanical

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engineering work [2] reported on an analysis of professional engineering practice. Twenty-one engineers from a range of organizations, educational backgrounds and career stages were interviewed. The interviews were audio-taped, transcribed and analysed using a dedicated, qualitative research, software package to reveal a rich picture of mechanical engineering practice. Six different types of work were now identified: problem solving, craft work, supervising, liaising, networking and integrating. These types were then located on a typological map constructed on two orthogonal dimensions, one defining either the technical, organization or personal aspects of a company's operation and the other categorizing the power relationships in which the individual engineer worked, namely apprentice, colleague, mentor or sponsor. Interpreted in this way it became apparent that careers in mechanical engineering typically involve a substantial shift from an early focus, under close supervision, on technical issues to concerns that are essentially to do with human relationships, concerns exercised with significant independence. Overall the analysis pointed to the need for a whole range of competencies in a developing and changing career, many of which lie outside a technical world view.

This paper turns to those competencies. The paper on content and process [1] assumed a close-in vantage point to look at specific details of mechanical engineering work. The second, on an analysis of practice [2] took a middle distance view of the types of work which engage the mechanical engineer. The current paper, the third in the series, steps back further, broadening the field of view to encompass the general competencies displayed by engineers in all of their roles. It begins with a review of contributions, especially those of Vickers, Schein and Schon, on the essential, defining attributes of professional work in general. It then distils these analyses to propose an interrelating pattern of generic competencies demanded in mechanical engineering practice with suggestions of how the exercise and balance of those competencies might change as a career develops. It concludes with a call for the reassessment of the philosophic base of mechanical engineering education.

PROFESSIONAL WORK

There is an extensive literature on the idea of professionalism, generally adopting either a technical, sociological or institutional perspective. In a report on an investigation of engineering education in the USA over the period 1923–1929 [3], for example, professional work in engineering was seen as involving activities of an expert character, concerned with planning, designing, establishing methods and examining projects. This technical interpretation included in professional practice major administrative activities involving not only the application of engineering methods and requiring a background of technical knowledge, but also an executive ability of a more general order. Rothstein [4], on the other hand, saw professions as communities held together by certain values and norms, shared by all members of the profession. Lewis and Maude [5] came to the conclusion that 'a moral code is the basis of professionalism'. Merging the technical with the sociological, Barber [6] characterizes the professions with a body of knowledge, a service orientation toward society rather than individual self-interest, a code of ethics and pecuniary rewards which are an end not a means towards self-interest. From an institutional standpoint, Prandy [7] noted that most authors cluster the values involved in the idea of professionalism around two concerns. The first is 'the desire to hallmark the competent', so that those who use their services have some guarantee that certain tasks are performed adequately. The second concern is that members of a profession give a guarantee of integrity by undertaking to conform to a code of conduct, with expulsion from the membership as the final sanction.

Now while these interpretations say something about the nature of professionalism and about the relationship between professions and society, they do not illuminate the sort of competencies demanded of professionals in their work, nor distinguish between professional competencies and those exercised in other human activities, if any such distinctions exists. Vickers [8], in contrast, was vitally interested in the special qualities required of professionals. In distinguishing 'the professional from the mixed class of client–employer on the one hand and from the rest of the self-supporting populace on the other' he identified six elements: understanding, designing, advising, operating, knowledge and judgements.

Distinguishing elements of the professional (Vickers)

To Vickers, a professional has a special skill in understanding some types of situations, for example, doctors in understanding human biological order and disorder. Vickers associated these skills with systems analysis. The professional also has a special skill in designing 'new situations within the limits set by (the) conditioning laws of the system'. Such systems design skills are clearly exhibited by architects and engineers in situations where there is a wide scope for choice of structural shape within the limits imposed by site, materials and laws of stability. Vickers claimed that skills in understanding and designing gave the professional special authority in advising and, since advising skills could be distinguished from the first two he added advising to the repertoire. He regarded these three skills as distinctly professional.

The fourth skill, operating or doing, Vickers described as essentially 'technological', but still an important attribute of the professional. This skill is used by a doctor, for example, in intervening in the biological systems of concern by drugs and surgery, but there are also standards of excellence by which such work is judged. For the engineer, operating would include computational, modelling and analytical skills and project management abilities. Vickers was concerned that sometimes the emphasis on operating or doing and the amount of technology available to support these activites could obscure the need for understanding, designing and advising.

The fifth characteristic of the professional for Vickers was special knowledge. This knowledge is essential to underpin the professional's roles as understander, designer, operator and, together with something more, as adviser. Once again Vickers saw a danger that specialized knowledge could become so bulky, difficult and remote that it became to be seen, by layperson and professional alike, as *the* mark of the profession, swamping other important attributes. In fact, the something more mentioned above seems to be the most important quality of all.

Vickers called this quality the capacity for judgment, the sixth professional ability. According to him, 'understanding, designing, advising and operating with their partly common background of theoretical knowledge and practical experience are the basic abilities of the professional. But in exercising them, he needs to be able to judge the professional requirements of his role in relation to his client, the public, and his fellow professionals.' Vickers thus recognized an ethical obligation as well as an intellectual challenge in professional work, demonstrated through the central element, professional judgment.

While Vickers wrote of the nature of professionalism in general from personal experience gained in a long career in law and public service, Schein [9] launched a specific study in 1961 to investigate the interaction of professional values and career events for a selected group of graduates of the Sloan School of Management. From this study he introduced the concept of career anchor, 'a syndrome of motives, values, and self-perceived talents which guides and constrains the person's career'.

Career anchors (Schein)

Schein [9] identified two sets of 'anchors' of a career in professional management. On the one hand a career 'is anchored in a set of job descriptions and organisational norms about the rights and duties of a given title ... On the other hand, the career is anchored in a set of needs and motives ...'. Schein classified his panelists into five types, named to reflect the major motive or need underlying the anchor, namely managerial competence, technical–functional competence, security, creativity and autonomy–independence. His basic theme was that organizations need to recognize the different kinds of contributions that people can make and develop multiple reward systems as well as multiple career paths to permit the full development of the individual. The concern here with the study is to elucidate the elements of professional work that the interviews with this group of managers uncovered.

The first group, under the managerial competence title, understood their careers to be organized around three things: interpersonal competence—the ability to influence and control people in the achievement of organizational goals, analytical competence—the ability to solve problems under conditions of uncertainty and emotional stability—the capacity to be stimulated by the assumption of power. The talents of this group were exercised on complex organizational issues rather than focused on specific regimes of knowledge. The second group, under technical–functional competence, were, in contrast, thoroughly absorbed by the technical challenge of the work they were doing. The specific area of expertise remained of great interest to this group, even as their career progressed. They tended to resist translation from technical to managerial activities.

The fourth group described by Schein can perhaps be seen as linking anchors concerned primarily with doing (1 and 2) and those (3 and 5) reflecting the interaction between individual values and the work environment. Respondents under this classification, creativity, expressed 'a strong need to create something of their own' [9], but within a business environment. The invention or development of something new, whether a product, process or service, is what really interested these professionals. The links with anchors 3 (security) and 5 (autonomy and independence) are evident in the responses of this group since the very act of creation seemed to satisfy a need to be free of organizational constraints, to be recognized for one's individual efforts.

Groups 3 and 5 related their career paths to the directions their own preferred development should take. Respondents classified under type 3, security, were prepared to allow the employing organization to define desirable competencies for their role in return for a sense of security and belonging. Very often such people were called on to work in the technical–functional arena, rather than to rise to higher levels of management. On the other hand, the graduates classified under anchor 5 were primarily concerned with their own sense of freedom and autonomy and found organizational life to be too restrictive. Some of these independently minded people also chose to pursue their development as technical–functional specialists, but in a consulting capacity.

There are several points of contact between Vickers' six distinguishing elements and the talents and values underlying Schein's five career anchors. The role of special knowledge is clear for the managerial competence, technical–functional competence and security anchors, types who related strongly to the employing organization, but also for the creativity and autonomy–independence anchors which embraced professionals who preferred to work more independently. Vickers' operating skill is evident as a base for effective contribution in types 1, 2 and 4, while understanding and designing appear as important characteristics in anchor types 1, 4 and 5. The place of personal judgment in complex issues, based on consistent and appropriate values, is particularly apparent in types 1, 4 and 5, confirming Vickers' emphasis on the need to exercise sound judgment. The web of connections is illustrated in Fig. 1. Thus, professional work, for both Vickers and Schein, employs special knowledge and expertise firmly grounded in a set of motives and values.

Schon [10], however, adds another dimension to this dual structure of talents and values, seeking to establish an epistemology of professional practice based on 'an examination of what some practitioners (including engineers) actually do'. He is particularly concerned with the dynamics of professional practice in a world characterized by complexity, uncertainty, instability, uniqueness and value conflicts.

Reflective practice (Schon)

Writing in 1983 Schon [10] argued that effective professional practice in real world situations crucially depends on skills and know-how that can only be acquired through 'reflection in action'. Schon claims that professionals, in day-to-day practice, make innumerable judgments of quality and display skills which are largely dependent on tacit recognitions of the special features of a particular situation. This 'tacit recognition' is built up by professionals thinking about what they are doing, sometimes even while doing it. Schon says:

> Stimulated by surprise, they turn thought back on action and on the knowing which is implicit in action. They may ask themselves, for example, 'What features do I notice when I recognise this thing? What are the criteria by which I make this judgment? What procedures am I enacting when I perform this skill? How am I framing the problem I am trying to solve?' ... There is some puzzling, or troubling, or interesting phenomenon with which the individual is trying to deal. As he tries to *make sense of it* (my italics), he also reflects on the understandings which have been implicit in his action, understandings which he surfaces, criticises, restructures, and embodies in further action.

It is this active process of reflection-in-action which is central to the 'art' by which practitioners sometimes deal well with situations of uncer-

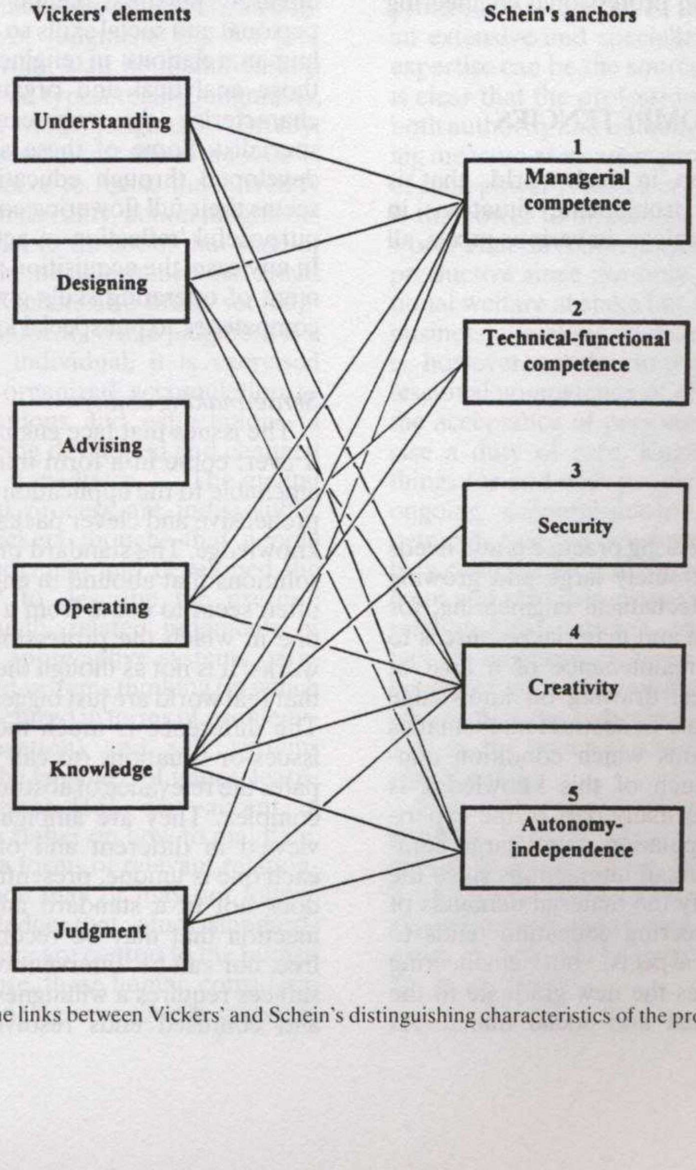

Fig. 1. The links between Vickers' and Schein's distinguishing characteristics of the professional.

tainty, instability, uniqueness and value conflict. [10]

To Schon this 'art' is to do with problem setting rather than problem solving and in fact he considers that problem setting is a necessary precondition for the employment of the technical problem solving skills that professional education focuses on. To him problem setting is a process in which, interactively, we name the things to which we will attend and frame the context in which we will attend to them. He describes the topography of professional practice in terms of a 'high, hard ground where practitioners can make effective use of research-based theory and technique' and a 'swampy low land where situations are confusing "messes" incapable of technical solution'. However, in the swamp reside the problems of greatest human concern while those on the high ground, while perhaps of great technical interest, may be largely irrelevant to society. Dealing effectively with swampy messes depends on the capacity to make sense of complex issues and this capacity adds a further dimension to professional competence.

Drawing together these themes, from Vickers, Schein and Schon, five distinct, but interrelated competencies can be discerned, general enough to be considered generic in professional engineering practice.

GENERIC COMPETENCIES

Effective intervention in real world, that is human and complex, problematic situations in engineering practice employs, in various mixes, all of these competencies:

(1) special knowledge,
(2) operating skill,
(3) sense-making ability,
(4) sound judgment,
(5) wise direction.

Special knowledge

Contemporary engineering practice is and needs to be based on an extremely large and growing body of knowledge. Mechanical engineering, for example, directs human and material resources to the manufacture and maintenance of a host of products and processes, drawing on knowledge from regimes as disparate as abstract mathematics and the cultural fashions which condition consumer preferences. Much of this knowledge is highly technical, not normally part of the experiences of the wider population, but a large component is to do with human interactions since the engineer exists to satisfy the material demands of the community. Engineering education tends to emphasize technical aspects, but engineering practice quickly exposes the new graduate to the realities of the personal and social milieu. As Vickers noted, however, the technical knowledge base of a profession (such as engineering) may be so extensive and so inaccessible to the non-specialist, that it is accepted by practitioner and public alike as the defining characteristic of that profession. It is important to recognize then that the competency of special knowledge does not lead to effective intervention in itself. It certainly provides the essential fabric on which the patterns of professional practice may be stitched, but the creation of those patterns demands much more.

Operating skills

The practising engineer needs to be able to call on a wide range of mental skills, associated at times with a well-developed manual dexterity. For example, the ability to visualize objects in three dimensions and to manipulate such shapes 'in the mind's eye' is fundamental to mechanical design. Such visual thinking skills find expression in and are in turn enhanced by the sketching of ideas on any available medium. Few engineers can resist the urge to explain and develop their ideas for designs by drawings. This may be a distinguishing characteristic of the engineering profession that Vickers, as a lawyer immersed in a verbal tradition, did not appreciate. Across the spectrum from this intensely personal mental activity are the interpersonal and social skills so essential to productive human relations in engineering. In between lie those analytical and organizational skills which characterize the engineer as a technological specialist. Some of these skills may begin to be developed through educational programs but it seems their full flowering comes from ongoing and purposeful 'reflection-in-action', as Schon puts it. In any case, the acquisition and thorough development of operating skills gives rise to an essential competence to put special knowledge to use.

Sense-making ability

The issues that face engineers in practice rarely, if ever, come in a form immediately and usefully amenable to the application of even the most comprehensive and clever package of skills and special knowledge. The standard problems with their neat solutions that abound in engineering science texts often seem to come from a different world to the one in which the professional engineer lives and works. It is not as though the problems that arise in that real world are just bigger or more complicated. The difference is much more fundamental. Real issues or situations (to call them problems anticipates the relevance of abstraction and isolation) are complex. They are ambiguous, capable of being viewed in different and often contrasting ways, each one is unique, presenting its own form which does not fit a standard and any action or even inaction that may be recommended is not value free, nor can be. Intervention under these circumstances requires a willingness to accept conflicting and confused ends resolved 'through the non-technical process of framing the problematic situation that we may organize and clarify both the ends to be achieved and the possible means of achieving them' [10]. Now while Schon describes his process of naming and framing, of 'making sense of messes', as non-technical it is certainly not haphazard. Checkland's [11] soft systems methodology was developed precisely to deal with such ambiguous and problematic issues. The process of engineering design too is itself designed to make progress through uncertainty and it is in design that the student engineer first faces situations which are by nature open-ended. For the engineer in practice, it is this competence of making sense of complex issues that enables knowledge and operating skills to be brought to bear appropriately. This third competence is thus an enabling one, to be exercised with careful consideration and judgment.

Sound judgment

Vickers, [8, 12] interpreted the mental skill of judgment in the sense of the concept of responsible choice, a 'decision which is personal yet made with a sense of obligation to discover the rules of rightness applicable to the particular situation' [8]. There is no doubt that sound judgment is an important quality in a professional, perhaps most clearly evident in managerial roles, but it is a somewhat elusive quality since 'the appraisal of judgment is itself an act of judgment' [8]. To give structure to this important skill he identified and distinguished three broad types: reality judgments, action judgments and value judgments. Briefly, reality judgments are assessments about the state of affairs out there and serve to revise the currently accepted view of external reality, action judgments are concerned with what to do about that state of affairs and value judgments determine what result is most to be desired. Vickers also firmly set judgment in a social environment. While judgment is a mental activity of an individual, it is exercised within 'a vast, partly organized accumulation of largely shared assumptions and expectations, a structure constantly being developed and changed by the activities which it mediates. . . . The mental activity and the social process are indissoluble' [12]. Nevertheless, Vickers thought that people could be trained in judgment and developed the idea of 'appreciation' to describe the exercise through time of mutually related judgments of reality and value. His appreciative systems paradigm complements hard systems thinking (in which methodologies are structured in terms of problems, solutions and optimization) and soft systems thinking (which talks the language of issues, learning and accommodation) [13]. The accent in appreciative systems is rather on how to maintain, modify or elude certain forms of relevant relationships, from which action may or may not follow. The paradigm acknowledges that values, standards and perceptions of reality are central to the human experience. Furthermore, these human considerations are dynamic, changing over time in response to a flux of events and ideas. Vickers considered that a person's capacity for making appreciative judgments was largely conditioned by his or her 'readiness to see and value things in one way rather than another' [12] and that that readiness was in turn the product of past experiences in appreciation, to be modified, however, slightly, by the next experience. The quality or soundness of judgment, leading to wise decisions, depends very much on the individual's mental framework and moral values developed over time.

Wise direction

Acting wisely, in the professional context, can be interpreted in part as the responsible and productive exercise of power. Bacharach and Lawler [14], in an analysis of power and politics in organizations, distinguished two types of power: authority and influence. Authority is based on the structural sources of power, on the position of the individual in the hierarchy. A professional having authority typically controls resources, the prerogatives that he or she assumes are sanctioned by organizational rules and the position itself gives access to and control over exclusive knowledge. Influence, on the other hand, may be exercised independently of hierarchical position and derives from sources such as personality, expertise and opportunity. In professional work, given the central importance of an extensive and specialized body of knowledge, expertise can be the source of significant power. It is clear that the professional engineer will possess both authority and influence and usually in increasing measure as a career progresses. The proper use of such power is then a crucial competence since it is the power to direct that initiates all engineering work. That direction must be both responsible and productive since not only is personal and institutional welfare at stake but also engineers are in the business of making an enterprise successful. There is, however, another important aspect to the professional competence of wise direction and that is the acceptance of personal responsibility to exercise a duty of care. Engineering is about doing things for and with people and the successful and ongoing accomplishment of engineering tasks demands that the development of all stakeholders be a central concern. There is a need for commitment and skill in constructing and maintaining the relationships between production worker and factory engineer, between client and consultant, between junior and senior engineer, for example, to ensure that the individual profits in the broad as well as the material sense from being associated with the task.

Now although all professional engineering work employs each of these five competencies to a greater or lesser degree, the substantial shift away from technical issues towards human relationships experienced in engineering careers [2] suggests that some of them will be more prominent than others at various stages.

GENERIC COMPETENCIES AND CAREER DEVELOPMENT

Schon [10] argued that the view of professional knowledge which has most powerfully shaped both our thinking about the professions and the institutional relations of research, education and practice is that of technical rationality. According to this model, Schon says, 'professional activity consists in instrumental problem solving made rigorous by the application of scientific theory and technique'. He singled out engineering (and medicine) as a profession which can clearly be associated with this view and there is no doubt that the idea has driven the development of curricula in engineering schools in most countries since the Second World War. Most engineering courses begin with a solid diet of mathematics and basic science and lead on to the application of these to problem solving in the engineering sciences. The emphasis is on acquiring incontrovertible factual knowledge to be used in convergent and well-conditioned solution processes to arrive at the correct answer. Subjects such as design or management, which offer some glimpse of open-ended solutions and human issues, do not fit the rationality mould and have either been ignored or converted to respectable design or management science. To the graduates of such programs, engineering becomes characterized by specialized, but selected knowledge and a toolkit of analytical techniques, mostly based on the computer.

For engineers graduating from such an environment and entering industrial employment for the first time, the transition can come as quite a shock. Typically, the tasks new engineers are given will be more like Schon's 'messes' than the clear cut problem solving experiences they have been used to. The responses to this new world, fully of ambiguity and uncertainty, vary. The responses of one group is to explain the fact that the tasks cannot be tackled in a straightforward way by applying the toolkit to facts and figures, by complaining that their employer is not giving them real engineering work to do. The group who feel that way may grumble that hardly any of what they have been taught appears to be of any use or even interest to their boss, despite their being the proud possessors of the latest technical advances. There is a perceived mismatch between what the new graduate is good at and what the situation in industry demands so the obvious conclusion is that industry is backward. Another response is to recognize, with excitement and enthusiasm, that the poorly structured messes they have been presented with offer this second group a great opportunity to put their own stamp on things. They find that what they do know is useful and relevant, but only after a process of problem setting which calls on an approach quite different to their core educational experiences. Probably most of the new engineers fall somwhere between these two responses, sometimes frustrated and sometimes stimulated, but in any case finding out that there is much to learn about engineering practice after school.

It seems to me that this stage of an engineering career lasts approximately 5 or 6 years, with perhaps one or more job shifts. It is a time when the ways of thinking engendered and developed throughout the educational process are expanded and modified by the experiences of practice. By the end of the period the engineer has emerged as a specialist in his or her own right and is recognized as such by professional colleagues. Simon [15] observed that the gestation period for many professions is approximately 10 years from the beginning of tertiary education so that the medical graduate of a 6 year course plus a year's supervised residency reaches a level of competence comparable to the specialist engineer after a further 3 years' practice. Perhaps this is the best way to define the first stage of an engineering career, combining the educational experience with its absorption in an applied, 'industrial' culture to produce a technically competent professional, a specialist.

Many engineering alumni, on return visits to academe, report that after 5–10 years in practice their job has moved away from technical matters towards management. Most see this as desirable because they have observed that it is in the management stream that the real power and rewards lie. This experience is so general that it seems to define a distinct second phase in an engineering career. The engineer, as manager, still has a keen interest in technology but it is its effective application in a business world that now dominates day-to-day work. The decisions that have to be made are more concerned with what tasks ought to be tackled and by whom rather than the details of how. During this phase many seek to further their formal education, but mainly in business administration or organizational and personal behaviour. Technical expertise is now set in a broader context, but that context is largely taken as given, with policy determined by others.

The capacity and opportunity to develop policy marks the third and most advanced stage of an engineering career. By this time, beginning perhaps some 15 years after graduation, the engineer is expected to play an active role in determining company objectives and to represent those objectives to other institutions. The company is identified by the individual professional who is known to be able to speak for it. Within the company the engineer, as director, has increasing responsibility and power to influence the development and career progression of newer employees, both to enhance institutional productivity and to encourage development of individual potential. There may be little opportunity for purely technical work but all of what he or she does is informed by the experiences and growth of the previous stages. The nature of the tasks that engage the professional engineer is now very different indeed to that of the first job, demanding a rich appreciation of the complex interaction of technical, economic and social issues.

Set against this broad brush picture of career development, it is clear then that the mix of generic competencies, acquired and required, will also change over time as the professional's role in an engineering business expands. In the early stages, knowledge and operating skills will predominate as the engineer works under direction in an unfamiliar environment. The growing capacity to discriminate the relevant and opportune elements of a confused and ambiguous business 'mess' builds a firm foundation for the sensible deployment of those skills and knowledge. This foundation deepens and stabilizes as the abilities to make sound judgments and offer wise counsel are forged and sharpened through practice and commitment. Figure 2 shows this interpretation of the developmental establishment of the structure of professional engineering practice. The horizontal axis is a rough time–career stage scale, suggesting that for most engineers career progression is through experiences gained over some elapsed time. Given the magnitude and time-span of many engineering endeavours, it is probably not easy to condense or accelerate that progression very much. The vertical axis represents growth in professional competence, in terms of both an expanding level of skill in separate competencies and of a richer capacity gained by the addition of new competencies. It is obviously not meant to imply a quantitative measure. However, at any career stage the relative contributions that each of the generic competencies makes to practice is intended to be represented by projections on to that axis. The placing of the axes is not meant to suggest dependence or independence since career advancement might both engender new competencies and depend on their development. The areas of the regions on this 'map' occupied by the five generic competencies, special knowledge, operating skill, making sense, sound judgment and wise direction, are again essentially qualitative representations but the change in their relative size over time is intended to be meaningful. Furthermore, the content in each region will not remain static but will be continually refreshed and expanded as new knowledge, skills and so on are gathered into the competency mix.

The map proposes therefore that full professional capacity is reached only after some time in practice through the progressive introduction and expansion of a set of distinct competencies. As each competency is added, the ones which have been exercised earlier acquire a more secure basis. There is a synergy operating vertically across the regions which enhances and transforms the old through the introduction of the new, but it is practice itself that leads to these more mature developments.

ENGINEERING EDUCATION

If it is mainly through practice and intelligent reflection on practice that the professional acquires and expands the competencies that are fundamental to excellence in engineering work, then the philosophies currently underlying engineering education need to be seriously questioned. The idea that engineering is 'instrumental problem solving made rigorous by the application of scientific theory and technique' [10] is firmly entrenched in the minds of the engineering faculty. Not only does it provide the rationale for contemporary educational programs but it also underlies the whole structure of engineering research in universities wherein research appears to be legitimate only in so far as it adopts the scientific model. Research and teaching in engineering are thus comfortable companions, since the faculty are most likely appointed on their research record. So we have a situation where would-be engineers are exposed to an academic culture which does indeed prize excellence, as it should, but excellence in a

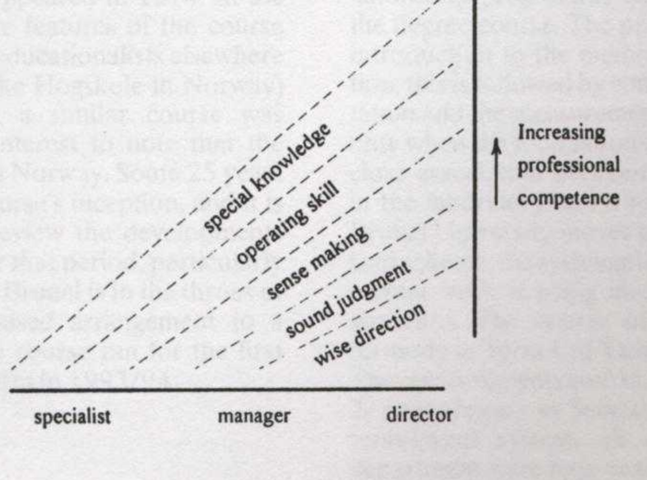

Fig. 2. The development of the mix of competencies throughout an engineering career.

restricted set of professional competencies. One has to ask how well such a culture prepares the graduate engineer for excellence in practice in Schon's swamp.

If universities really aim to equip the graduate for a journey along the path of professional development then it is high time to point engineering education in an entirely different direction. Other professions, notably medicine and architecture, may show the way. That direction is through the landscape of professional practice. Engineering students enter engineering schools to be engineers and the large majority of them go on to employment and service in industry. It is the responsibility of academe to value such aspirations and to ground the educational experience in the reality of professional practice. If it does not, can engineering continue to claim to be a profession?

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