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On the Nature of Mechanical Engineering Work—Foundations of Practice*

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This paper argues that the intellectual foundations of professional mechanical engineering courses in universities ought to be in practice, rather than in scientific research. It constructs a foundation of practice, beginning with a base of intellectual development on which is built, in turn, learning, scholarship and competence to underpin practice. The four levels of support form a consistent philosophical set. The paper adopts a scheme of development proposed by Perry, in which students modify the way they see the world over time and experience, through several stages from dualism, through multiplicity and relativism to commitment. It describes learning in terms of Kolb's experiential model, defining four different forms of knowledge and four learning styles. An expanded vision of scholarship, reported on by Boyer from the Carnegie Foundation, adds the scholarships of teaching, application and integration to that of research. Then the links between development, learning, scholarship and competence are sketched to propose a hierarchical model of the foundations of practice. The paper concludes with the identification of the challenge facing engineering faculty: to establish an academic culture that values practice as well as research, and that guides the student engineer towards the highest levels of professional competence

INTRODUCTION

IN THE previous paper in this series on mechanical engineering work [1] it was argued that excellence in professional practice is grounded in a set of generic competencies, namely special knowledge, operating skill, sense-making ability, sound judgement and wise direction. Furthermore, it was suggested that the professional acquires and expands these competencies over time, mainly through practice and thoughtful reflection on that practice. The idea that a professional develops competence through practice is certainly not new and some professions, notably medicine, architecture and social work, maintain 'clinical' experience as a central bulwark in their educational programmes. Mechanical engineering, however, and perhaps every other branch of engineering, does not. The focus of most mechanical schools is on engineering science and on 'instrumental problem solving', to use Schon's [2] phrase, in engineering science. The foundations of science lie in research, not practice.

The influence of the research model in engineering education is pervasive. Dixon [3], for example, in building a case for the introduction of doctoral programmes in engineering design, traced the evolution of engineering science education over the past 50 years. For Dixon, course development follows a well-established path: 'The content originates in research . . . publications disseminate the information . . . a graduate course is created . . . understanding and codification of the knowledge allows (an elective) course to be introduced to undergraduates. . . . Textbooks appear . . . the material [is] included as a core undergraduate requirement' [3]. Dixon lays the blame for the United States' poor record of converting its wealth of new scientific discoveries into internationally successful products on the fact that the best engineering design practices are not widely used in its industries. He urges that a strong infrastructure for design be developed and argues that design should follow the 'proper path' travelled by the engineering sciences. That is, the best way to improve engineering design in practice is to strengthen its scientific research base in academe. Now while such a move might enhance the standing of design faculty in engineering schools and even, in the long run, see design as a discipline accorded a status equal to that of the existing engineering sciences, it seems to lead design, an activity central to engineering practice, into a familiar impasse. Training in the engineering sciences by a faculty immersed in the scientific research culture is already the dominant education model for many schools. The content of many of the courses offered in those schools already has its origin in engineering or basic science research. But as engineers in industry well know [4], engineering science and the precise techniques for the analysis of the models of the world it provides, constitute only a small part of the special knowledge and skills demanded in day-to-day practice.

This is not to suggest that design, or any other engineering task for that matter, should not be firmly grounded in engineering science. It is absolutely essential that the engineer deals in the

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realities of materials and their responses under load, in the realities of electrical, chemical and thermodynamic processes, for example. The engineering sciences, and the research that engenders them, have a singular role in building useful models of those realities. But the accomplishment of engineering tasks, always within a social and economic context, engages the practitioner in forms of work other than instrumental problem solving. A previous study [4] identified craft work, liaising, supervision, networking and integration, for instance—activities that demand a range of competencies which, while central to professional engineering practice in industry, may be peripheral to the researcher. It can be argued, therefore, that the path for course development in education programs aimed at turning out professional engineers ought to begin 'process and content originate in *practice*'.

There are encouraging signs that the research model in tertiary education in general is being subjected to scrutiny. Not only has it had an enormous influence on course structure and content for nearly half a century but research has become the very *raison d'être* for the majority of academic staff. Rewards and status go to those who excel in research, excellence measured in terms of research grants and publications. Now there are strong calls for a rethinking of this state of affairs, notably by Boyer [5] in a special report from the Carnegie Foundation, entitled 'Scholarship Reconsidered'. This paper will turn to Boyer's broader view of academic endeavour later but first it attempts to draw together some ideas which might underpin the concept that practice ought to provide both the foundation and binding cement for building a professional engineering course.

PRACTICE AND DEVELOPMENT

If special knowledge can be considered the outcome of a research-based curriculum, then professional competence is the aim of a practice-based one. While it may be possible to define a particular quantum of knowledge a student can reasonably be expected to have been exposed to by the end of the course, it is clear that a practice-based structure will have a goal of a quite different nature. Professional competence is extended and enhanced through engagement in engineering tasks in employment so the goal of a practice-based program must be to set the individual upon a path that encourages and enhances the development of competence. That path needs to have its starting point and direction defined throughout the educational experience but most of the journey along it will be beyond the borders of that experience. The energy for that journey may come in part from a mentor in the workplace but primarily it must be generated and renewed by the individual. A fundamental consideration for practice must therefore be the intellectual development of the individual.

Culver and Hackos [6] were also interested in developing a more effective educational programme to better prepare engineering students for professional careers. They defined such a programme as 'one that would promote student intellectual growth and maturity, as well as basic knowledge and skills'. They believed that traditional content-based courses did not achieve that goal, and recommended Perry's [7] model of intellectual development to engineering educators. In the 12 or so years since that call, engineering courses have, if anything, become more research and content-based but Perry's model, with its focus on development through the university years, remains particularly relevant to education for practice. The work belongs in the stream of educational ideology stemming from the Dewey–Piaget cognitive-developmental or interactional view. The interactional view asserts that 'cognitive processes emerge through a process of development that is neither direct biological maturation (Rousseau, Freud) nor direct (environmental) learning in the usual sense (Locke, Watson, Skinner), but a reorganisation of psychological structures resulting from organismic-environmental interactions' [8].

During the 1950s Perry [7] undertook a study to determine how liberal arts students responded to the intellectual and moral atmosphere at Harvard. The atmosphere was intended to challenge the students' assumptions about their world, and so the study encompassed both development and ethical dimensions. Perry recorded nearly 100 interviews over a four-year period, observing 'a common sequence of challenges' which faced each student and to which each student responded in particular ways. This led Perry to formulate a model for the sequence of intellectual development [9]. Eight years later another class was followed through its experience of college and the overall progression appeared congruent with that traced in the original study [10]. Perry could say that 'the course of cognitive and ethical development . . . appears to be a constant phenomenon of pluralistic culture' [10].

The scheme of development proposed by Perry and his co-workers defined nine positions or stages of interpretations of meaning. Each position represents 'a meaningful way of construing the world of knowledge, value and education' and 'each position both includes and transcends the earlier ones, as the earlier ones cannot do with the later. This fact defines the movement (from one position to the next), as development' [10]. The nine sequential positions, and the transitions between them, signpost a path from dualism, through multiplicity and relativism to commitment. The following excerpts from Perry [10] define these terms:

Dualism Division of meaning into two realms—Good versus Bad, Right versus Wrong etc. Right answers exist *somewhere* for every problem, and authorities know them. Right Answers are to be memorised by hard work. Knowledge is quantitative.

Multiplicity Diversity of opinion and values is recognised as legitimate in areas where right answers are not yet known. Opinions remain atomistic without pattern or system. No judgement can be made among them so 'everyone has a right to his own opinion; none can be called wrong'.

Relativism Diversity of opinion, values and judgement derived from coherent sources and patterns allowing for analysis and comparison. There will remain matters about which reasonable people will reasonably disagree. Knowledge is qualitative, dependent on contexts.

Commitment An affirmation, choice or decision (career, values, politics, personal relationship) made in the awareness of Relativism (distinct from commitments never questioned). Agency is experienced as within the individual.

The journey along this path is one of the major accomplishments of students, according to Perry. They progress from a simple dualistic view of life and knowledge towards a more complex, rich and mature view. They begin with values and attitudes borrowed from authority figures (parent, priest, professor, etc.) and move to becoming their own person, capable of assembling evidence from a variety of sources, interpreting and testing that evidence against their own understandings and making a judgement about what meaning can be attached to the resultant integrated picture. Progress along the path will clearly have a great deal to do with the acquisition and enhancements of a professional capacity since it is these very competencies of assembling special knowledge and data, of interpreting and making sense of the ensuing pattern, of exercising sound judgement about what it all means in its special context, and of making a wise response, that lie at the heart of professionalism. It can be argued, therefore, that a practice-based course on engineering would need to build on such a model of individual intellectual growth, one that 'combines a psychological theory of development with a rational, ethical philosophy of development' [11]. As Stephenson and Hunt [11] also pointed out, making the leap from the adoption of a cognitive-developmental theory to specific intervention in instruction is most difficult (they reported on a successful attempt in two social science classes) but, nevertheless, developmental theory provides a convincing and enabling foundation for engineering education, offering a real alternative to the research-based model currently in vogue.

The divergence of the two models, research and development, is particularly apparent in the role *content* plays in each. The research model places content at the centre of course structure. The developmental model sees a focus on content as a manifestation of early stages of development, to be later set in a broader context of generalized process, at a higher level of abstraction. The focus shifts from 'what' to 'way' [10], and a way of thinking and learning, rather than specific knowledge or skill, is the course goal. So the second level of ideas for course construction—to build on a developmental foundation—will need to draw on concepts of practice and learning.

PRACTICE AND LEARNING

If competence in practice is seen as arising out of individual intellectual development, then the centrality of the relationship between practice and learning is clear for, as Kolb [12] wrote, 'learning is . . . the process whereby development occurs'. There is a consistency of fundamentals here since Kolb's ideas on learning, like Perry's on intellectual development, have their origins in the works of Dewey, Lewin and Piaget. Furthermore, Kolb's model of the underlying structure of the learning process again, like Perry's work, combines concepts from both psychology and philosophy, although Kolb explicitly adds physiology. This paper therefore takes Kolb's theory of experiential learning as an appropriate framework for exploring the interactions between practice and learning.

The idea behind Kolb's interpretation of learning is that it requires both a 'figurative representation of experience and some transformation of that representation' [12]. He gives equal status to the prehension and transformation processes, holding them to be complementary but different dimensions of learning. Each of these dimensions, Kolb suggests, is bounded by dialectically opposed adaptive orientations. Thus the prehension process may draw either on comprehension, a reliance on conceptual interpretation, or on apprehension, a reliance on immediate experience. Transformation may occur through intention, i.e. internal reflection, or through extension, manipulation of the external world. Associating the adaptive orientations in pairs led Kolb to define four 'basic knowledge forms' [12], set out here in Table 1.

Table 1. Kolb's basic knowledge forms

Adaptive orientations	Basic knowledge form
Comprehension–intention	Assimilative
Comprehension–extension	Convergent
Apprehension–extension	Accommodative
Apprehension–intention	Divergent

According to Kolb the distinguishing characteristics of these forms are as follows:

- Assimilative—concerned with ideas and abstract concepts rather than people; derives from inductive reasoning and the creation of theoretical models.
- Convergent—concerned with technical tasks and problems; based on problem solving, decision making and the practical application of ideas.
- Accommodative—depends on interaction with people; adapts approach to suit circumstance and absorbs new experiences comfortably.
- Divergent—engages the imagination and feelings; serves to integrate a variety of experiences into a meaningful whole.

Kolb went on to demonstrate that individuals might exhibit a preference for one or other of these basic forms in organizing and building their understanding of their world, leading to the concept of learning style (or relatively stable adaptive orientation). An individual's preferred learning style was thought to be fairly enduring, although 'there is a general tendency to become more analytic and reflective with age' [12]. He also tentatively linked preferred learning style with career choice, suggesting that 'career choices tend to follow a path toward accentuation of one's specialised approach to learning' [12]. Furthermore, Kolb considered that each of the learning styles, by itself, had a certain incompleteness about it, and that higher levels of learning emerged from various combinations of the elementary modes, the highest level being attained when all four were combined. It is to these last two findings of Kolb, the 'starting point' of a career and the combinational development of learning capacity, that this paper now turns.

It has already been argued that the dominant mode of enquiry espoused in engineering schools derives from the scientific tradition. Particularly in the early years, most engineering curricula focus on mathematics, physics, chemistry and introductory engineering sciences. In examining the relationships between the structure of learning, the structure of knowledge and fields of enquiry, Kolb firmly linked the natural sciences and mathematics with the assimilator learning style (pairing comprehension and intention). The sort of mental activities involved in assimilation are organizing information, building conceptual models, testing theories and ideas, designing experiments and analysing quantitative data [12]. Recalling the set of generic competencies that have been postulated to underpin professional engineering practice [1], it is apparent therefore that special knowledge and, to some extent operating skills, will have their foundations laid through engagement in the assimilator learning style. Later in an engineering course, however, as problem solving in engineering science applications becomes dominant, there will be a need to further develop operating skills based on specialized knowledge so that another learning style might become more useful. Kolb associates his convergent style with the science-based professions, describing its main attention as on decision skills rather than on thinking skills. It is concerned with 'creating new ways of thinking and doing, experimenting with new ideas, choosing the best ways of thinking and doing, experimenting with new ideas, choosing the best solution to problems, setting goals, and making decisions' [12]. Certainly practising engineers, particularly recent graduates, often find themselves working on projects that require both decisions and thinking skills in fairly structured environments. It may be postulated then, that as new competencies are demanded and required there is a concomitant shift in learning style focus. The 'starting point' capacity (assimilation) remains but another one (convergence) is added to the mental framework that conditions interpretations of the world.

While Kolb commented on the incompleteness of each of the basic learning styles, taken singly, it is also true that each of them possess certain strengths. For instance, the movement from a concentration on assimilation to a convergent way of learning empowers the student (and practising engineer) in the *application* of knowledge in a structured way. Similarly, the extension of learning into the accommodative style might be seen as better equipping the engineer to deal with unstructured situations, where there is a need to adapt to, and take action in, changing or messy circumstances. In such circumstances the knowledge and skills developed from assimilative and convergent learning may no longer fit the immediate facts, yet decisions may still need to be made. Kolb sees the greatest strengths of the accommodative style as 'in doing things, in carrying out plans and getting involved in new experiences' [12], and links it to the social professions. The ability to work effectively under conditions of uncertainty, encapsulated within the competency of sense-making, thus emerges from building this way of learning and thinking into the professionals' mental framework.

A further cumulative progression to the divergent learning style brings yet another element to that framework. Kolb relates enquiry and endeavour in the humanities and social sciences to divergence, and associates this learning style with valuing skills: 'being sensitive to people's feelings and to values, listening with an open mind, gathering information, and imagining implications of ambiguous situations' [12]. An acknowledgement and feeling for the beliefs and values that underlie the behaviour and motivations of the stakeholders in engineering tasks is certainly a prerequisite for exercising sound judgement and offering wise direction, the remaining generic competencies. Added to assimilation, convergence and accommodation, this style thus provides a counterbalancing personal perspective to the essentially technical and organizational ones that flow from these others. Furthermore, with its focus on integrating a variety of experiences into a meaningful whole, it leads to a deeper understanding of issues, setting the engineer's role within a broad context.

To return to the metaphor of intellectual and professional development as a journey along a path, the picture presented here, then, is that the competent professional gains that competence over time on journeys through a learning landscape in which different regions offer different vistas. For the engineering student the journey might begin in the familiar region of assimilation (special knowledge), be guided through the neighbouring territory of convergence (operating skills), become increasingly more self-directed through initial explorations in accommodation (sense-making ability) and lead at least to an awareness of the land of divergence (sound judgement and wise direction). After graduation, throughout a professional career, the landscape will be frequently revisited, each new visit covering more of the territory, with the traveller in a frame of mind better informed by the achievements and challenges of professional practice. Just as it is necessary to study every region to form a coherent map of the whole, so the professional will need to establish the generic competencies through continual exercise of the four learning styles in an integrated and integrating framework. At the beginning of these travels, however, it is the culture within academe which will largely determine whether the new graduate is well enough equipped to undertake that first, independent, mental journey of discovery.

PRACTICE AND SCHOLARSHIP

It has already been observed that the influence of the scientific research model in professional engineering schools is widespread. It belongs to a value system which, as Rice [13] says, continues to be normative for the majority of faculty in most university disciplines. Within that value system it is assumed that 'research is the central professional endeavour and the focus of academic life' [13]. That such a view gives rise to a very restrictive conception of scholarship has long been recognized and there has been an ongoing, sometimes acrimonious debate about the relative importance of teaching and research in universities. Of particular relevance to the themes developed here, however, is that it is only recently that the arguments have been pressed further to include discussions of the scholar's role and the university's responsibility for the application and utilisation of knowledge' [13]. Boyer [5] also recognized the need for an expanded view of scholarship, believing that the 'tired old teaching versus research debate' did not reflect the full range of academic and civic mandates that define the work of academics. It is to his reassessment of the role of university and college faculty that this paper now turns to set up the third level of support for a practice-based course in engineering.

Boyer [5] argued that it is time to give scholarship, a 'familiar and honourable term', a broader meaning, one that 'brings legitimacy to the full scope of academic work'. His report, based on extensive surveys of American universities and colleges with a wide range of missions, identified four separate, yet overlapping functions of the professoriate, namely the scholarship of discovery; the scholarship of teaching; the scholarship of application; and the scholarship of integration. A summary of his commentaries on these four elements follows [5]:

Discovery The scholarship of discovery (or research) is central to the work of higher learning. It requires a commitment to knowledge for its own sake, to freedom of enquiry and to following, in a disciplined fashion, an investigation wherever it may lead. The pursuit of knowledge enlivens faculty and invigorates higher learning institutions. The discovery of new knowledge is absolutely crucial.

Teaching Without the teaching function, the continuity of knowledge will be broken and the store of human knowledge dangerously diminished. Teaching both educates and entices future scholars. Teaching is the highest form of understanding. It is a dynamic endeavour involving all the analogies, metaphors and images that build bridges between the teacher's understanding and the student's learning.

Application The scholarship of application moves towards engagement as the scholar asks 'How can knowledge be responsibly applied to consequential problems?' It is based on the principle that higher education must serve the interests of the larger community. Application is serious, demanding work, requiring rigour and accountability. Theory and practice vitally interact, and one renews the other.

Integration By integration is meant making connections across disciplines, giving meaning to isolated facts and putting them in perspective. It means fitting research outcomes into larger intellectual patterns. It asks 'What do the findings mean?' If carefully pursued, the scholarship of integration can lead the scholar from information to knowledge and even, perhaps, to wisdom.

While Boyer was particularly concerned with the acquisition of knowledge, and concluded that it could be acquired in these four connected ways, the same four elements of scholarship are also fundamental to the use of knowledge. The relationship between professional competence in practice, the expanded vision of scholarship and learning becomes clear from the work of Rice [13]. It has been proposed earlier, under practice and learning, that the set of generic competencies that underlie professional practice can be variously associated with Kolb's different forms of knowledge and learning styles. Rice [13], coming from a different direction, argued that recent enquiries into the structure of knowledge and alternative approaches to learning made transparent the connections between Kolb's learning classifications and the Carnegie Foundation's enlarged understanding of scholarship reported by Boyer. Rice [13] mapped those elements of scholarship on Kolb's adaptive orientations, defining the scholarship of discovery as grounded in comprehension–intention (assimilation), the scholarship of application in comprehension–extension (convergence), the scholarship of teaching in apprehension–extension (accommodation) and the scholarship of integration in apprehension–intention (divergence). So there is a developmental connection between generic competencies and learning styles through the forms of scholarship. Also just as special knowledge, operating skills, sense-making ability, sound judgement and wise direction tend to be acquired and demonstrated in that order, so too does the scholarship energizing that process follow the pattern discovery, application, teaching and integration. Once again there is a consistency of fundamentals here to link learning, scholarship and competencies.

The role and responsibility of university faculty in creating a culture in which the use of knowledge in practice is accorded equal status to the generation of knowledge by research is thus quite central. It is their professional attitudes and ways of thinking that will make the connections for the student between competence and learning. If faculty remain absorbed in one particular form of scholarship, to the exclusion or marginalisation of the others, then those connections cannot help but be partial. It is they who will establish the topography of the landscapes through which the student and graduate engineer will travel, directly affecting the quality of that journey, particularly in the formative early years.

The overall shape of the foundations of a practice-based course can now be seen.

FOUNDATIONS OF PRACTICE

Figure 1 shows how the various concepts discussed form the foundations of practice. In this model there are four levels to that foundation: development, learning, scholarship and competence. The most fundamental is the ongoing intellectual development of the individual. Successive levels give effect to and direct that development towards the achievement of excellence in professional engineering practice. Thus the effectiveness and broadening of learning styles stem from the construction of more meaningful ways of construing the world. In turn scholarship, in its various forms, focuses that capacity to learn into first specific disciplinary knowledge and skills and later into more widely grounded competencies. Finally competence, developed appropriately to match career tasks, underpins all good engineering. Thus the vertical dimension may be defined as enablement. At each level there is also a pattern of change from left to right, one that is characterized by a growing ability to imagine, cope with and be energized by an increasingly complex world. The horizontal dimension might thus represent richness of interaction with the world. The guiding

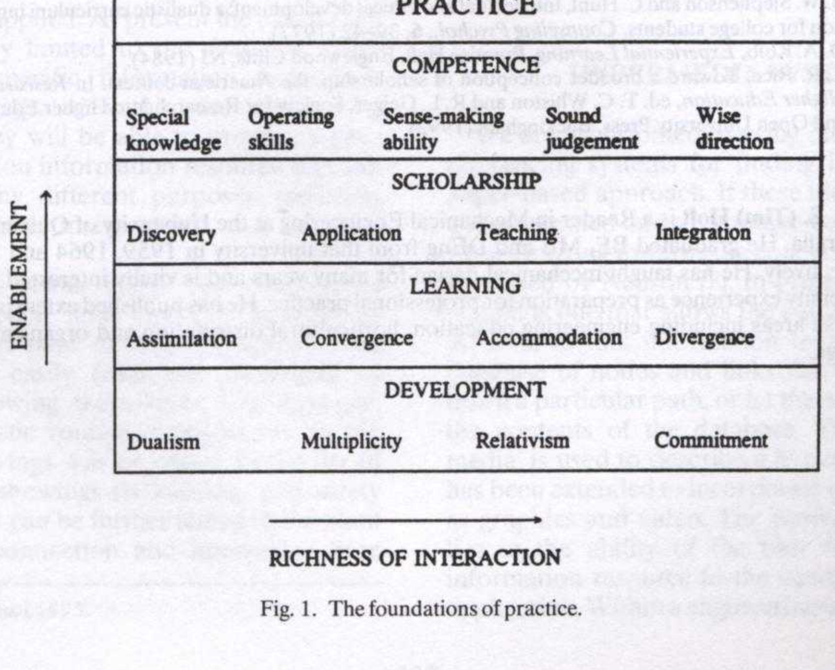

Fig. 1. The foundations of practice.

principle behind a practice-based course in engineering then might be concurrent movement along these dimensions towards the goal of excellence in professional practice.

The juxtaposition of the elements across the boundaries of each level is not meant to be significant. For example, excellence in research leading to high standards of special knowledge may draw on all the different learning styles, grounded in a rich personal intellectual development that effectively integrates mature views of the world. Similarly the exercise of sound judgement and the capacity to give wise direction in professional practice would engage all the forms of scholarship to focus the four complementary learning styles, again based in maturity. Perhaps this model of the foundations of practice maybe best thought of as a mosaic which is progressively completed through practice and reflection, by filling out each part to build a sound and robust mental framework for professionalism.

CONCLUDING REMARKS

This paper began with the claim that the intellectual foundations of the courses in most mechanical engineering schools are those of scientific research. It was not always so. Prior to the 1950s, courses were often founded on practical experience and empirical rules of thumb. There can be no, and ought not to be any, going back to those days. The subsequent 'scientification' of engineering has brought with it an enormously significant and powerful intellectual base. But the developments have been lopsided for the particular and equally significant intellectual foundations of engineering practice have gone largely unrecognized and ignored. And yet the vast majority of the graduates of our schools find employment in industrial practice. Therein lies the challenge to contemporary and future academe: to weld together the old and useful pragmatism, the clear thinking of engineering science and the sheer competencies of engineering practice. These foundations of practice might help to stimulate that progress.

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