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# The Nature of Academic Work in Engineering*

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*The paper examines the nature of academic work in engineering in the context of the many stakeholders to whom universities are accountable and the multiple foci on which university staff concentrate their activities. The distinctive characteristics of academic work are identified, and analogies drawn between the processes of innovative thinking in universities and research and development in engineering industry. Methods are proposed for the objective tracking of academic careers. The paper provides a conceptual framework for the description and analysis of academic work to ensure that both engineering academics and university leaders have a deep understanding of the special nature of their responsibilities. Such an understanding is a necessary pre-requisite for intelligent leadership in engineering education.*

## INTRODUCTION

THE UNDERLYING theme of this paper is intelligent leadership of engineering education in universities. We address this theme by exploring the nature of academic engineering work in the belief that intelligent leadership of any human enterprise, including universities, demands a deep understanding of the nature of that enterprise by those who lead it and those who participate in it [1]. The paper draws extensively on the career and experience of the first author (WPL), a career in a state-funded university in an English speaking country. By focusing on one career in depth we hope to obtain insights not revealed by more broadly based investigations; this in turn provides the basis for identifying and discussing issues relevant to the operations of all universities and the ways they discharge their responsibilities for education and research in engineering.

Of concern is the superficial knowledge of academic work often displayed by university leaders and government policy makers. Many examples could be cited to illustrate this point; three from the authors' experience will suffice here. In November 1994 the Council of the University of Melbourne published an internal document entitled 'The Responsibilities of University Staff' [2]. This document prescribed, inter alia, that 'Staff members must work only on university-related activities during working hours'. In so far as academics are liable to use any of the 168 hours available each week to pursue their intellectual interest in their university work this is indeed a remarkable statement. It conforms to a view of work as something that only occurs in a time and place controlled by someone else [3]. Nowhere in the document are there references to the advancement, interpretation and dissemination of knowledge, all key responsibilities of university staff. If we turn to the political arena we find academics have to reconcile the conflicts in calls by governments 'to put students first' (the Australian Minister for Education, Employment and Training, August, 1997 [4]) and recommendations that 'universities be required to increase their external funding for applied research by 50% by the year 2005' (Mortimer Report to the Australian Minister for Industry and Science, August, 1997 [5]), all of these things to happen with significantly reduced levels of government funding. Academics who look to government committees of enquiry for enlightenment do so in vain, at least in Australia where the West Committee, appointed by the Commonwealth government to review higher education policy and funding, published a discussion paper [6] which said a lot about consumers and consumer choice, globalisation and the possible impact of information technologies, but nothing about the work of academics and the engagement of the minds of thoughtful people in matters of intellectual substance.

Our aims then in this paper are to investigate the nature of academic work and establish its leading characteristics, then to examine implications for the conduct of university affairs and evaluations of university performance. We wish to elucidate the nature of scholarly activity in education and research, and by so doing draw attention to the dilemmas facing university leaders and academic staff at a time when the funding levels provided by governments are being dramatically reduced. While the paper is directed towards university Departments of Engineering (because that is where our experience lies), we

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hope that the experimental evidence presented and the arguments adduced will advance the conduct of university affairs in other disciplines as well.

We begin with a description of the academic activities undertaken by engineering staff in universities and an analysis of the factors which motivate their work. The evidence is based on the work diaries of the first author and analyses of academic workloads made by the other authors. Further evidence provided by observations of the first author's academic career is then presented. Patterns of intellectual endeavour are identified and modelled, and implications for higher education discussed. The foregoing is then combined with other descriptions of academic work reported in the literature in order to identify key characteristics affecting the conduct and performance of university work. This leads to a discussion of issues related to evaluation and assessment and the application of benchmarking techniques. Attention is drawn to matters directly affecting both academic careers and universities' performance but which are not amenable to benchmarking. Universities' mode of operation is compared with that of successful innovators in industry to help identify the risks and uncertainties to which academic staff and their leaders are inevitably exposed. We conclude with statements summarising the outcomes of this investigation and the insights obtained. The results represent essential inputs to intelligent leadership of the modern university.

## ANALYSIS OF THE NATURE OF ACADEMIC WORK

### *Academic activities—identification and classification*

In 1995–96 the authors, working independently, prepared separate compilations of the activities undertaken by engineering staff [7, 8]. An agreed final listing drawing on both these sources is given in Appendix 1. This listing is sufficiently comprehensive for our purpose and is in general agreement with accounts given by other educational researchers, e.g. [9]. Appendix 1 contains 55 individual activities organised into 4 major categories with 2 to 5 sub-categories in each major category. The justification for the classification adopted in Appendix 1 is twofold, theoretical and experimental.

1. *Theoretical.* Universities exist for the advancement and dissemination of knowledge and categories 1 and 2 correspond to these functions. Academics interact with their colleagues in their own and other universities, and through their university with society at large; they thus engage in and provide the service functions listed in category 3. Underlying the execution of all these functions are the supporting activities which comprise the intellectual infrastructure set out in category 4.
2. *Experimental.* One of the authors (WPL) has successfully used a very similar classification to record and analyse the times devoted to various academic activities in his work diaries for three typical years [7]. The other authors have successfully adopted a classification similar to that in Appendix 1 in an internal analysis of staff workloads [8].

### *Academic imperatives*

The contents of Appendix 1 derive from the functions of a university. The successful conduct of the activities listed in Appendix 1 is an outward, visible expression of the inherent satisfaction academic staff find in their work. Sympathy for staff motivation is a key factor contributing to intelligent leadership of universities. Our experience leads us to express motivation in terms of 'academic imperatives', the essential intellectual and emotional needs which drive academic action in university schools of engineering. We deduce from Appendix 1 the academic imperatives set out below; the section of Appendix 1 to which each imperative relates is given in brackets at the end of the relevant statement.

- The need for *rational discourse*—as a basis for ordered and coherent undergraduate courses and curricula (Undergraduate education—current).
- The need for *continuous improvement*—for the progressive development of courses, curricula and the means for presenting them (Undergraduate education—future).
- The need for *exploration*—for extending and redefining the boundaries and content of one's discipline (basic and strategic research).
- The need for *relevance*—for associating one's academic work with the leading edge of contemporary professional practice (applied research, technology transfer).
- The need for *collegiality*—for service to others in the university community (service to the university).
- The need for *social cohesion*—for service to the wider community outside the university (public service).
- The need for *intellectual nourishment and renewal*—for on-going relationships with national and international groups of scholars (academic infrastructure).
- The need for *reflection*—for self-awareness of the intellectual foundations of one's work (academic infrastructure).

## AN ACADEMIC CAREER IN ENGINEERING

A longitudinal study of WPL's academic career over several decades reveals patterns and cycles of events and linkages of activities not previously reported in the literature. The results of such a study are presented here, followed in later Sections by analyses and discussion of the leading characteristics of academic work in Engineering as exemplified by this and related experimental evidence.

*Patterns of intellectual endeavour*

Are there any recurring patterns of events leading to significant academic outcomes which we can identify and from which we can construct a more general picture of the nature of academic work in engineering? One pattern of events that has been replicated several times in WPL's career is shown in Table 1 where the numbers in the left hand column of the Table indicate that event No. 1 led onto No. 2 and then onto event No. 3 and so on. The progression of events is illustrated by the contents of three columns. The left-hand column lists the type of activity engaged in, the middle column gives a particular instance, the right-hand column identifies the general pattern. It will be clear to the reader that in this aspect of WPL's academic work the world of industry and practice is being used as the laboratory, in an endeavour to make progressively deeper analyses from the series of one-off experiments that is life. The series of exchanges of information and ideas between consultancy, research and education is a notable feature of Table 1. We would argue that engineering schools in universities should so organise themselves that such exchanges are facilitated. It should perhaps be mentioned that as well as the external impact identified in item 8 there is of course the 'internal impact', the accumulation of knowledge and experience which underpins a continuously developing academic career.

In Table 1 each item clearly leads on to the next. Sometimes life is as simple as this, but often it is not. The notion of a career trajectory is introduced in the next Section to illustrate this point.

*Career trajectory*

One of the tools employed by researchers in technological innovation is the concept of 'technological path' which traces the arrays of prior events leading to the innovation. For example, Garud and Rappa reported a deep analysis of the development of cochlear implants by 3M in the United States and Nucleus in Australia [14], in which the research team set up a database listing the critical events leading to the launching of their new products by each company. The story was a complicated one and the database eventually contained over a thousand entries.

In the same way one can identify the critical events leading to some, significant, identifiable academic output. To illustrate, presented in Fig. 1 is an analysis of selected parts of WPL's academic career showing the interacting paths by which significant outcomes were reached, exhibiting the result in the form of a 'career trajectory'. The notation used in Fig. 1 is as follows.

- small rectangle: denotes critical event in path to outcome;
- small circle: denotes presentation of conference paper;
- large circle: denotes publication of refereed journal paper or chapter of book;
- large rectangle: denotes knowledge gained from an investigation;
- horizontal arrow: denotes scholarly activity leading from one critical event to the next;
- vertical arrow: denotes flow of knowledge derived from one event or strand of investigation to application in another.

There are twelve strands of thought and investigation leading to observable outcomes, usually published papers, chapters of books. These outcomes have been selected because they provide objective data capable of independent verification. This is not to deny that there may be other outcomes at least as important as those in Fig. 1, but not capable of being captured in a relatively simple diagrammatic form, notably matters of the inner life, the world of the spirit, the empathies developed with students and colleagues.

Figure 1 represents a post hoc analysis, but is

Table 1. Pattern of activities in an academic career in engineering

| Type of activity | Instance | General pattern |
|---|---|---|
| 1. Consultancy | Design of critical component for power transmission | Interaction with engineering problem solving in industry |
| 2. Educational R&D | Compilation of case study [10] based on consultancy | Development of new teaching materials for developing professional skills |
| 3. Educational innovation | Use of case study in engineering course | Implementation of new material for teaching and learning |
| 4. Analysis of results of innovation | Analysis of student responses case study | Educational research |
| 5. Publication of results of analysis | Presentation of paper at conference [11] | Presentation at conference on engineering education |
| 6. Engineering research | Analysis of information flows in component design using data from case study | Further research based on experimental evidence and arguments developed in prior activities |
| 7. Publication of results of research | Authorship of chapter of book [12] | Publication in permanent form |
| 8. Impact | Citations, e.g. [13] | Citations by other researchers |

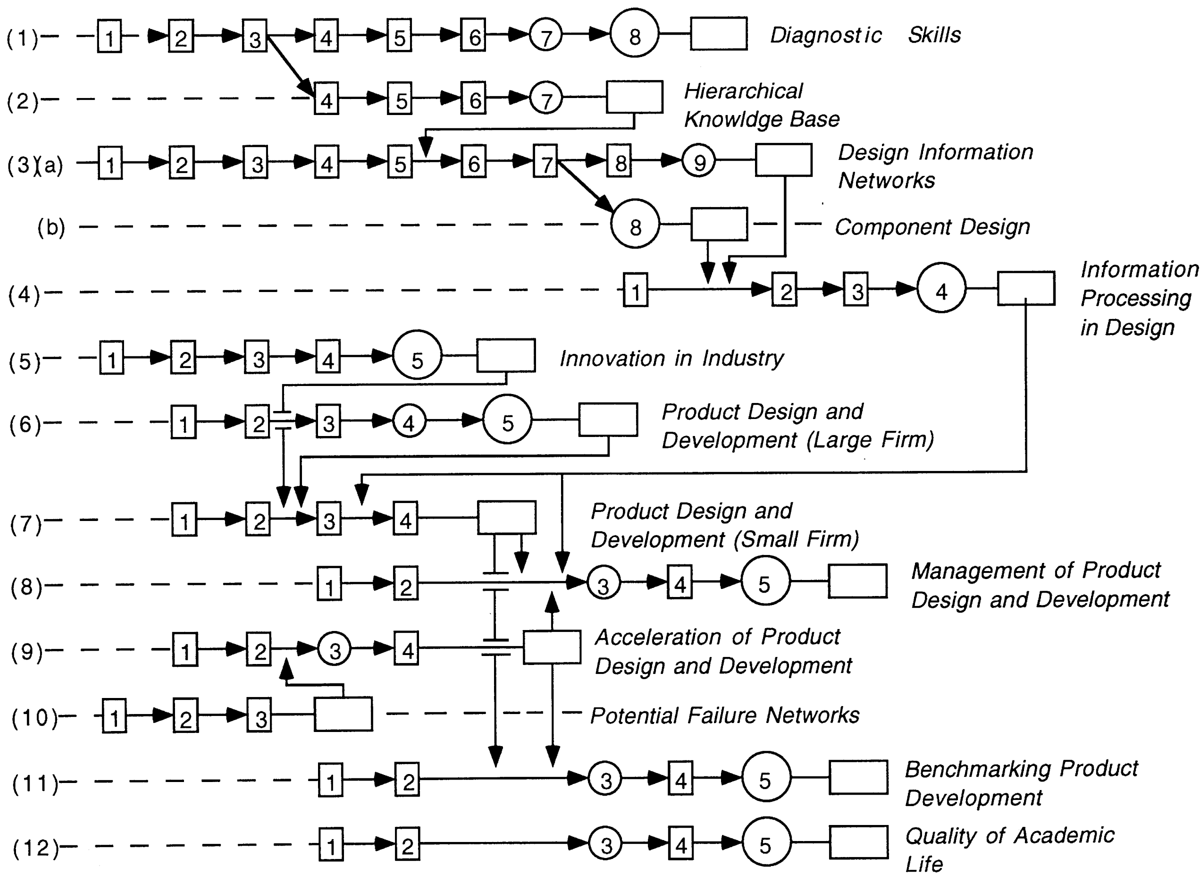


Fig. 1. Career trajectory, 12 strands of thought and investigation from WPL's career.

justified in terms of Kierkegaard's aphorism that 'Life has to be lived forwards, but can only be understood backwards'. With respect to WPL's career, items have been selected which are typical and at the same time deal with matters of technical interest to the reader. Events are termed critical if their presence or absence exerted or would have exerted a major influence on the final outcome achieved. Details of critical events and outcomes are given in Appendix 2, where they are identified by the same numbers as appear in the rectangles and circles of the relevant strands of Fig. 1.

Table 2, to be read in conjunction with Fig. 1, summarises the nature of the twelve strands of thought and investigation, lists the starting point to each strand, and gives details of the external group (if any) with whom WPL interacted at the start of each investigation. All the strands except No. 12 have a recognisably close relationship with engineering design, the authors, field of academic endeavour. We draw attention to the diversity of starting points and the variety of external groups with whom there were interactions; networks of colleagues and peers in universities and industry played a major role, but there was also scope for the exercise of personal curiosity. The variety of sources stimulating university research is, we believe, a characteristic feature of academic work.

*Career matrix*

The existence of interactions in the form of exchanges of information between strands of thinking and investigation can be displayed on an interaction matrix. Figure 2 is the interaction matrix corresponding to the academic trajectory shown in Fig. 1. A cross in the cell corresponding the $i^{\text{th}}$ row and $j^{\text{th}}$ column is to be interpreted as representing the fact that there is a flow of information from strand $j$ to strand $i$. There are no entries in the diagonal set of cells running from the top LH corner to the bottom RH corner. The matrix in Fig. 2 is an abstract model of the interactions shown in Fig. 1. The matrix format has the advantage of being able to handle large numbers of strands and interactions, much larger and more complex than those represented in Fig. 1 which, after all, represents only a part of the career of one mature academic.

If there are no entries in the $k^{\text{th}}$ row and the $k^{\text{th}}$ column then the $k^{\text{th}}$ strand is a separate line of investigation independent of all the others represented in the matrix, e.g. strand No. 12 in Fig. 1 and Table 2. An academic may need judgement to decide whether to embark on some completely new investigation like this—will the probability of making a worthwhile contribution to the field be in proportion to the time and effort necessarily expended? It could be argued that in a well planned academic career all the cells immediately below the

Table 2. Strands of thought and investigation in academic trajectory

| Strand | Subject | Starting point | External group with whom there was interaction |
|---|---|---|---|
| 1 | Diagnostic problem solving, engineering practice | Consultancy (consultancy undertaken by second author) | Local industry (random) |
| 2 | Case study in diagnostics, engineering education | Same as for strand (1) | |
| 3 | Case study in component design, engineering education | Consultancy. | Local industry (random enquiry) |
| 4 | Information processing in engineering design | Personal curiosity | None |
| 5 | Innovation in Australian manufacturing industry | Approach by prospective Ph.D. candidate | Local network of scholars |
| 6 | Product design and development | Request for special course, continuing education | Local network of industrial contacts (large company) |
| 7 | Product design and development | Request for special course, continuing education | Local network of industrial contacts (small company) |
| 8 | Management of product design and development | Call for papers, international conference | International networks of scholars—engineering design |
| 9 | Product design and development | Call for papers, international conference | International network of scholars—engineering design |
| 10 | Potential failure analysis in engineering design | Approach by prospective visiting researcher | International network of scholars—engineering design |
| 11 | Benchmarking product development | Call for papers, international conference | International network of scholars—manufacturing |
| 12 | Quality of academic life | Personal curiosity | None |

empty diagonal should be filled, as this would show the progressive accumulation of knowledge being put to use in successive investigations: knowledge from the $i^{\text{th}}$ strand being fed into the $(i+1)^{\text{th}}$ strand and so on. R. G. Cooper's research into the successful management of new product development exhibits this characteristic, as the progressive publication of his investigations demonstrate, see for example the papers cited in [15]. Cooper's academic trajectory represents a productive and focused career.

SOURCE OF INFORMATION (Strand No.)

RECEIVER OF INFORMATION (Strand No.)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | – | | | | | | | | | | | |
| 2 | X | – | | | | | | | | | | |
| 3 | | X | – | | | | | | | | | |
| 4 | | | X | – | | | | | | | | |
| 5 | | | | | – | | | | | | | |
| 6 | | | | | | – | | | | | | |
| 7 | | | | X | X | X | – | | | | | |
| 8 | | | | | | | X | – | X | | | |
| 9 | | | | | | | | | – | X | | |
| 10 | | | | | | | | | | – | | |
| 11 | | | | | | | X | | | X | – | |
| 12 | | | | | | | | | | | | – |

Note: Cross in cell of matrix indicates flow of information between strands of intellectual endeavour.

Fig. 2. Career matrix corresponding to career trajectory in Fig. 1.

*Factors affecting research output*

Discussion of publication rate as a measure of research productivity may be construed as a predisposition in favour of quantity at the expense of quality. Nevertheless, it is an easily calculated measure of academic output and one that is widely used nowadays [16]. Graphing publication rate over a number of years yields insights into the some of the factors which have had a major influence on WPL's academic career. We follow precedent by counting a sole-authored refereed conference paper published in the conference proceedings as one publication unit. A refereed paper published in a reputable journal counts as two units. A book published by a reputable commercial publisher counts as ten units.

Figure 3 shows the number of publication units each year since 1980. There are two sets of results, the upper line for total number of units annually and the lower line for the number of archival journal and book publications. We draw attention to the following matters affecting publication rate:

1. Over the period 1988 to 1993 inclusive the total publication rate (TPR) averaged 3.7 units p.a., while the refereed journal publication rate (JPR) averaged 2.0 units p.a.
2. Prior to 1988 there was a lengthy period of low publication rate, arising from the time spent on administrative duties as chairman of department 1980–84 and the time taken for academic rehabilitation thereafter.
3. The low output in 1994 was due to the time

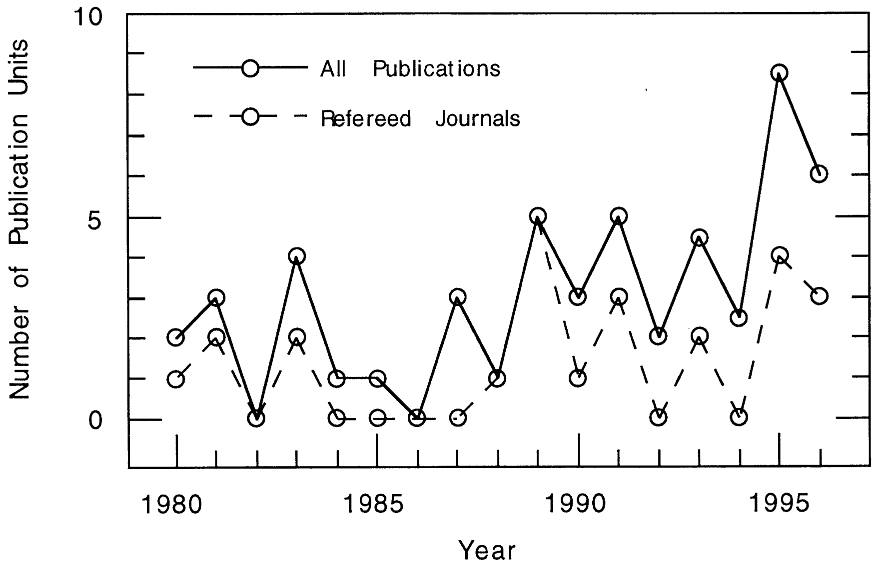


Fig. 3. Publication rate 1980–96.

taken to look after an elderly relative who was ill most of the year.

4. The upsurge in output in 1995–96 (TPR ~7.0, JPR ~3.5) has been the result of a conscious decision by WPL to re-organise his time and release 40% of it for independent work.

There is thus evidence of publication rate being affected by administrative responsibilities, extraneous family affairs, and the amount of free or uncommitted time. We would argue that an equitable procedure for assessing the performance of academic staff would take account of such extraneous factors.

## CHARACTERISTICS OF ACADEMIC WORK

Consideration of the foregoing and of the results of other research into higher education leads us to identify a number of characteristic features of academic work—features which differentiate academic work from professional endeavour in other professions.

### *Multiple foci*

Academics owe intellectual allegiance to discipline-based networks of peers at both national and international levels [17]. It is within these networks that they test out their ideas and gain recognition for their ever-increasing levels of expertise as they think more deeply about their discipline and contribute to its development. Furthermore, for academics in engineering, the contents of Appendix 1 illustrate a key aspect of academic life—the large number of groups of people and organisations, clients or stakeholders if you will, with whom engineering academics interact and to whom they have a responsibility for the successful performance of their academic work. The multiplicity of stakeholders provides multiple foci for academic effort.

The contents of Appendix 1 are now analysed to identify direct stakeholders, i.e. those groups of people explicitly mentioned in it to whom engineering academics owe some form of intellectual allegiance. The direct stakeholders so identified are listed in Appendix 3A together with statements of the relevant items in Appendix 1 from which they derive. Academic life is made complex not only by the fact that there are these 12 separate and distinct groups of direct stakeholders each with its own culture and world view but also by the fact that many of these groups contain multiple viewpoints. Thus if we restrict attention to employers of engineering graduates in industry and government, we find in the case of the authors' department that over any five-year period graduates proceed to around 150 different employing organisations. These in turn fall into the 20 major categories set out in Appendix 3B, each of these potentially a focus for academic action.

In addition there are indirect stakeholders—governments, politicians, bureaucrats, as well as members of society generally who may well exercise considerable influence on academic affairs from time to time. Items 2.4.1 and 3.4.2 in Appendix 1 imply the existence of such indirect stakeholders. The experienced academic acquires the judgement necessary to handle these multiple foci and to respond to the varying demands they impose. Nevertheless, there is an on-going dynamic tension underlying the academic process which may not be resolved to the satisfaction of all stakeholders.

The ever-present danger of having multiple foci for one's work is the consequent dissipation of academic effort over a broad range of topics when any major intellectual advance in a university discipline requires sustained, in-depth effort to achieve a successful outcome. Singh records that during the seven years Andrew Wiles needed to develop his proof of Fermat's last theorem he 'whenever possible would avoid the distractions of being a faculty member [at Princeton University] by working at home where he could retreat into his attic study' [18, p. 227]. Thus an essential component of the experienced academic's judgement is the ability to decide when to concentrate on important issues over extended periods of time and to schedule the 55+ activities of Appendix 1 so that this is allowed to happen. This is often easier said than done. In three typical years recorded by WPL in his work diaries only seven days out of the 300+ worked in each year were devoted to one particular academic matter of long-term significance [7], and in retrospect this is a matter for regret. It is a trap James Killian, a former president of the Massachusetts Institute of Technology, took care to avoid during his career in university administration [19, p. 19 and p. 138].

*Unpredictability*

In Fig. 1 most of the strands of thought and investigation led to a final outcome which was not predicted at the start of the exercise. One example of the unpredictability inherent in academic work will be given, many others could be cited. Strand No. 10 represents a line of investigation pursued by a visiting research fellow into the use of expert systems to identify potential failures in mechanical engineering systems and predict their consequences. The knowledge so gained was fed into a parallel research project which in due course led to a conference paper in 1993 [20]. It is fair to say that this paper made little impact at the conference as most experts thought that it was going over material that was already well known—end of that line of investigation, at least temporarily while WPL regrouped. However, discussions at the 1993 conference and subsequent correspondence with an MIT researcher enabled WPL to access research working papers from MIT's International Centre for Research into the Management of Technology, publications of which he had previously been unaware. Around 15 to 20 of these working papers are published each year; one of them, a reference cited earlier [14], introduced WPL to the concept of 'technological path' which in turn led to the construction of Fig. 1 and Appendix 2 and the discussion of academic trajectories. This outcome was not foreseen at the start of the investigation represented by strand No.10.

Many more instances of this phenomenon could be given, see for example Roberts [21] and Killian [19, p. 451]. An eminent social scientist began his most recent book (on leadership) with the words, 'In a way *I could never have anticipated*, my two most recent books led me to ponder the phenomenon of effective leadership' [22, italics added]. The world of scholarly enquiry is continually expanding the framework of our thinking, and proposing new interpretations and new insights. To accommodate unpredictability a measure of chaos is an essential feature of university governance (as argued in Section 5.2 below), but one not readily incorporated into currently fashionable styles of university operation which emphasise top-down management and accountability.

*Opacity of generic skill base*

Underlying most of the activities set out in Appendix 1 are high level skills, exercised by engineering academics as needed in the course of their work. But the skill base is opaque, and the identification of teaching skills in particular seems an especially intractable problem for many universities. To demonstrate that this need not be the case, we consider the pedagogic requirements of an engineering subject for which there is an agreed syllabus set out in an entry in a faculty course guide or handbook, and draw on the experiences reported in [23–27] to identify some of the key teaching skills in the subject.

- *Scope and objectives*. Setting the boundaries to the subject and delimiting it from other related subjects; and then having set the boundaries, knowing when to cross them or ignore them in order to put the particular subject in a larger perspective and demonstrate its relevance to students' aspirations and later careers. Many researchers in higher education have emphasised the importance of giving students realistic and meaningful educational objectives [23], and most course evaluation questionnaires include this as one of the key matters to be surveyed. Stating objectives in language which matches the mindsets and expectations of entering students requires a special skill, particularly when, as is usually the case in engineering, the final outcome of their studies comprises knowledge and understanding of new concepts with which they were initially unfamiliar. The complexity of the educational objectives in a professional skill-based subject in engineering and the difficulty of formulating concise statements of them is demonstrated by the example discussed by Samuel [24].
- *Cognitive strategy*. The knowledge and intellectual skill content of engineering subjects consists of sets of interlinking concepts and relations ranging from theoretical abstractions to concrete realisations of these abstractions in the form of hardware. There is a heavy cognitive load on students as demonstrated in earlier research by the authors. An engineering problem, one comparatively narrow and circumscribed by professional standards, was found to require for its solution a knowledge of 96 engineering and scientific concepts and skill in constructing and manipulating three different mathematical models to predict relevant aspects of system performance [25]. Cognitive maps are a convenient tool for representing the sequences

of and cross-linkages between concepts and relations in engineering subjects, noting, however, that typical engineering problems at undergraduate level are capable of generating quite complex maps [26, 27]. A high level of pedagogic skill has therefore to be exercised in selecting the order of presentation of individual concepts and relations, i.e. in tracing out a linear sequence through the complexities of the cognitive map representing the subject, with backtracks and reinforcements as considered appropriate for the level of student ability and experience.

- *Detuning problems from professional practice*. Professional problem solving in engineering is labour intensive. Some examples: the design of a new acoustic pump for submarine applications takes more than 500 person hours [28], the design of a new chemical plant for the manufacture of polyvinyl chloride may take around 10 000 person hours [29]. It thus becomes necessary to detune the complexities of professional practice for presentations in professional skill-based subjects in engineering courses. The skillful engineering academic selects key elements of professional problems for incorporation in student assignments, case studies and projects to provide stimulating exercises which can be completed within the time available in the undergraduate programme. The identification and selection of key problem elements and the assessment of the cognitive load their use imposes on students are important academic skills. Furthermore, these skills have to be exercised in a way which matches the varying levels of students' needs as they progress through their courses and learn to handle more complex, open-ended and poorly structured problems [30].

To sum up, academic staff are responsible—within the resources provided by their universities—for creating learning environments in which there is a creative tension between students' entering level of knowledge and expertise and the academic demands placed on them in their studies.

While we have attempted to shed some light on the pedagogic skills exercised by university staff in engineering disciplines, the subtle nature of these skills and the fact that their exercise is inextricably linked to the nature and content of individual subjects and the associated cognitive maps makes it difficult to gather observable, testable evidence of their use. It is not surprising that universities have found great difficulty in establishing valid criteria for promoting staff on the basis of their contributions to student learning [31].

## ISSUES RELATED TO THE CONDUCT AND ASSESSMENT OF ACADEMIC WORK

Matters relevant to the conduct and assessment of academic work are discussed in this section with particular reference to the intellectual well-being both of individual staff and of the university as an institution of advanced learning.

### *Performance indicators and allocations of time*

Public universities have to account for the effectiveness and efficiency of their performance to the governments who fund them, and many performance indicators and quality measures have been proposed for this purpose [23, 32]. There are few absolutes in higher education. Recourse is therefore had to benchmarking methods and techniques to provide measures of relative value, comparisons between universities on the basis of the outcomes of their academic efforts. The results are then given meaning by the inclusion in the benchmarking process of universities of established high reputation. The emphasis in such assessments on observable and measurable outcomes highlights the activities which directly lead to those outcomes; the intellectual fundamentals of the academic profession may be overlooked.

The authors draw on their personal experience to provide a case study to illustrate this argument. In the early 1990's the University of Melbourne embarked on a process of audits in which each academic department was reviewed and assessed by a team of international experts. The audit process involved reviews of extensive statistical data on the performance of the department and interviews with students, staff, postgraduates, graduates, employers, and with university and community leaders. The author's department was audited in August, 1995. Two months prior to this event a special report together with volumes of statistical data was compiled and forwarded to the reviewers. The special report was prepared by the head of department and a team of senior staff, and covered items deemed important by them as well as including matters stipulated in the relevant university policy document for the conduct of international reviews. The items covered in the special report are listed in Appendix 4; by and large they conform to Bourke's list of academic performance indicators [32], although compiled independently. We focus here on activities in Appendix 1 which do not appear in the tabulation in Appendix 4, i.e. are not *directly* related to observable academic outcomes. These activities fall into two groups dealing respectively with aspects of (a) academic infrastructure and (b) management and administration, as follows.

- *Academic infrastructure*. Activities 4.2, 4.3, 4.4, 4.6, 4.7, 4.8, 4.9—part of the underlying academic infrastructure—are absent from Appendix 4. These activities represent an investment of their time by academic staff. As with all investments there is an element of risk in that the benefits expected to accrue in the future may not outweigh the costs currently being incurred. The estimate of the risk involved is complicated by the fact that the current costs are directly measurable in hours and so can be assigned an explicit dollar value, whereas the future benefits may consist of intangible contributions to the development of educational and research programmes, e.g. by the informal 'accumulation of wisdom' [1, p. 75]. In the experience of one of us (WPL) activities 4.2, 4.3, 4.4, 4.6, 4.7, 4.8 occupy around 12% of the time devoted to academic matters in typical year with 2% devoted to industry liaison [7] (figures based on an average working week of 55 hours excluding travelling and meal time; activity 4.9 is discussed as a separate issue below). The authors consider that these percentages are appropriate in that they make possible the underlying intellectual input needed to sustain their educational and research programmes in the short term. However, there is a dearth of published data on the work patterns of successful academics against which these percentages can be benchmarked.

- *Management and administration*. Activities 1.1.4, 1.4, 2.4, and 3.1 which are not listed in Appendix 4 concern management and administration and represent an academic's on-going contribution to the administration and organisation of subjects, courses and curricula. They represent an overhead for which he/she receives no explicit recognition but which are essential to the conduct of academic affairs and to the generation and application of the collective wisdom of the departmental group. The time devoted to these activities by WPL decreased from around 11% in 1991 to around 8% in 1993 (the last year for which he kept records), perhaps an indication that collegiality in university governance is on the wane [33]. Be that as it may, author WPL considers that 8% is the irreducible minimum proportion of time devoted to administration and management by an experienced academic of reasonable seniority, but once again published data to confirm this judgement is lacking.
- *Time for reflection*. In the absence of experimental evidence to guide them academics continually exercise their personal judgement in the allocation of the most valuable resource available to them—their time. The danger here is that ill-informed judgements may be made by academics overwhelmed by the hurly-burly of day-to-day pressures. In this context we note that WPL's work diaries show no time spent on reflecting about and thinking through academic problems and issues, activity 4.9 [7]. This is something that should be an essential part of the academic infrastructure, but is all too often overlooked. Indeed, 'time for reflection is never mentioned in the endless exhortations relating to productivity targets, efficiency dividends and audits, to use some of the alien and graceless expressions thrust upon us by the economists' (Mason, former Chief Justice of the High Court of Australia, quoted in [7]).

*Innovation*

Some have argued that there are important lessons for university governance in the management practices adopted by successful companies in private industry. If analogies are to be sought between universities and private industry, we would argue that this should be done in the context of innovation—the creation, interpretation and dissemination of new knowledge in the case of the university vis-a-vis the creation of new products and processes in industry. In a comprehensive investigation into successful R&D in industrial product development, Cooper and Kleinschmidt [15] found that provision of uncommitted staff time was a characteristic feature of successful innovation in many companies. This finding is relevant to the operation of universities but, as far as the authors are aware, there has never been any attempt at systematic implementation in higher education.

In an earlier section, the concept of technological path or trajectory was introduced as a tool for displaying in a concise and informative manner the history of events leading to a successful innovation. To embed this concept in thinking about innovation we present an example from manufacturing industry—the development of the industrial lathe for the machining of metals by Henry Maudslay; the characteristics of this example can then be compared with those of the case study from academia given under 'career trajectory'. Analysis of Burke's historical account of Maudslay's work [34, p. 145] describes how Maudslay brought together and synthesised ideas from four separate strands of engineering development to achieve the final result: tools and toolmaking, advanced materials, manufacturing technology, and kinematic design. The relevant sequences of prior events and arrays of technological paths are shown in Fig. 4. Similar patterns of interacting strands of developing ideas are present in the academic trajectory exhibited in Fig. 1, e.g. the way in which strand No. 8 has direct inputs from strand Nos. 4, 7 and 9. When viewed at a sufficiently high level of abstraction, the processes of innovation in universities and industry are identical.

Thus when we look for analogies between universities and industry we find them in similar patterns of development in the processes of innovation. A university may then be conceived as a large R&D organisation where the 'products' are new ideas and new knowledge. But in private industry the management of innovation is fraught with difficulty. For example, Hounshell and Smith's study of the history of research in the Du Pont Chemical Company reveals the company as continually striving for the holy grail of successful innovation but never succeeding in finding the elusive strategy which guarantees success, this despite numerous changes of policy and procedures over the 80 years covered by their investigation [35]. On the other hand, a measure of chaos

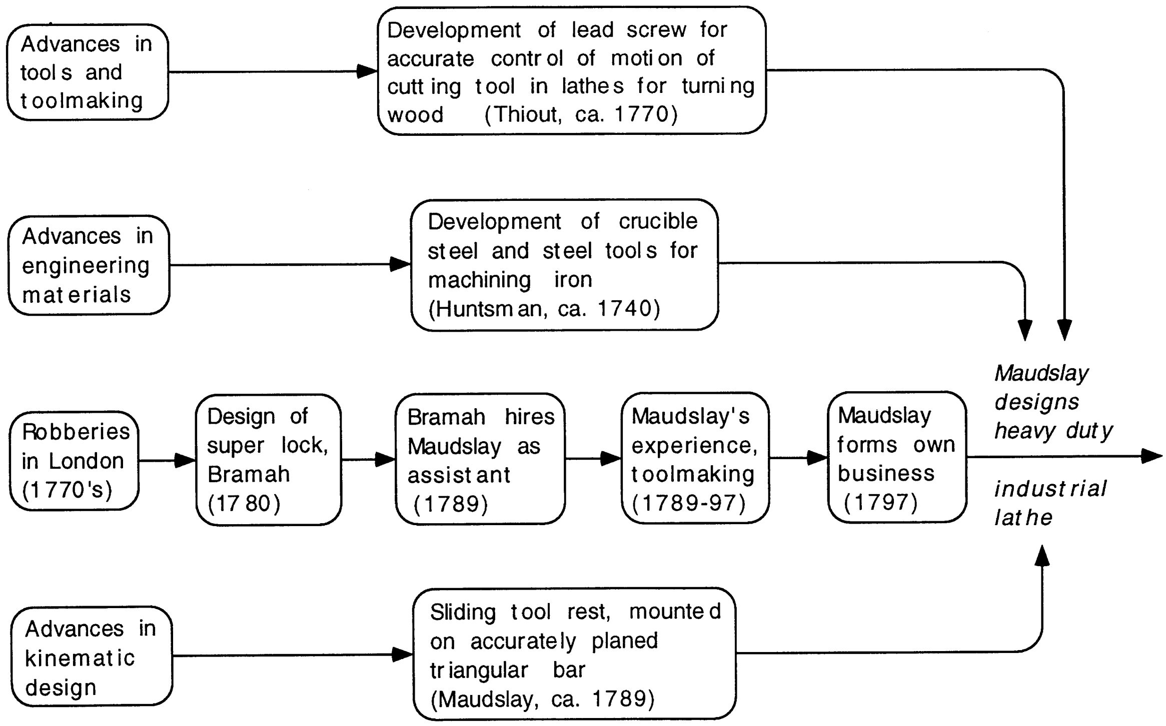


Fig. 4. Trajectory of innovation for Henry Maudslay.

has underpinned some of the great advances and discoveries made in universities: the juxtaposition of researchers from tenuously related disciplines played a significant role in the elucidation of the structure of DNA [36]; and Alan Turing worked unsupervised on his own to write his classic paper on computable numbers, inventing along the way the concept of a logical computing machine [37]. The general conclusion drawn by management consultants Peters and Austin is that the design of an R&D organisation must be predicated upon uncertainty and ambiguity, 'It's a thin line between discipline and chaos' [38, p. 192]. Positioning this line is a challenge, a never-ending challenge for university leaders.

## CONCLUSION

Our quest for a deep understanding of the nature of academic work in engineering has led to the following outcomes:

1. A coherent statement of the activities and responsibilities of academic staff in university schools and faculties of engineering, with activities classified in accordance with accepted theory and practice of university affairs.
2. Articulation of a set of imperatives hypothesised to motivate the academic work of engineering staff in universities.
3. Identification of a recurring pattern of intellectual endeavour in the work of an engineering academic in a professional skill-based discipline.
4. Demonstration of possible ways in which industrial consultancies, university research and undergraduate education interact and mutually support each other.
5. Establishment of the concepts of career trajectory and career matrix and demonstration of their application to academic careers.
6. Demonstration of the diverse nature of the factors capable of initiating university research.
7. Demonstration of extraneous factors capable of affecting an academic's research output.
8. Identification of distinctive characteristics of academic work in engineering as:
   (a) possession of multiple foci;
   (b) unpredictability of outcomes;
   (c) opacity of generic skills;
   and discussion of these characteristics in the context of academic performance and evaluations of academic performance.
9. Establishment of a set of typical performance indicators for benchmarking engineering departments.
10. Recognition of academic activities not amenable to benchmarking and proposals for allocations of time to them.
11. Demonstration of analogies between innovation in universities and R&D in industry, and discussion of the difficulties posed for the conduct of university affairs.

The essence of a university has been described by a classicist as 'the induction of the intellectually qualified into the rigours of rational discourse' [39, p. 21]. Rational discourse in engineering comprises a variety of languages and conceptual and methodological frameworks, drawing on mathematics, physical and social sciences, computing, professional skills and engineering practice as required. But engineering is more than discourse, it is disciplined action directed towards socially useful ends. From our investigation of engineering in universities, we have concluded that university systems of governance not only have to accommodate the multiple points of view of numerous stakeholders but also must be capable of responding to a rich diversity of intellectual stimuli and of adapting to and building on the unpredictable outcomes of intellectual endeavour. It is essential that university leaders, and indeed all academic staff, have a deep understanding of the nature of academic work and a robust conceptual framework for thinking and discoursing about university affairs. We hope that our paper has contributed to this end.

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## APPENDIX 1: ACTIVITIES PERFORMED BY ACADEMIC STAFF IN ENGINEERING

Set out below are activities which an engineering academic would be expected to undertake during his/her career.

1. *Undergraduate education*
Activities associated with the presentation of undergraduate courses and their on-going improvement and development from year to year.

**1.1 Preparation and planning**
1.1.1 Meetings and discussions with colleagues, the planning of innovations and improvements.
1.1.2 Preparation of course outlines, course notes, example problems, guided design exercises, assignments, laboratory experiments and demonstrations, computer-based exercises, projects, case studies, essay topics, quizes, notes for debates, notes for tutors.
1.1.3 Preparation for scheduled classes—audio-visual and computer aids, rehearsals, meetings with tutors to establish common educational rationale.
1.1.4 Organisation—liasion re room allocation, tutors, works visits, guest speakers, interfaces with related subjects.

**1.2 Delivery**
1.2.1 Face-to-face contact with students at scheduled times—lectures, tutorials, practice classes, laboratory sessions, project supervision, quizes, debates.
1.2.2 Voluntary tutorials and remedial teaching for students embarking on unfamiliar subjects.
1.2.3 Unscheduled student enquiries, 'blow ins'.

**1.3 Assessments, examinations**
1.3.1 Preparation of examination papers, marking schedules.
(a) Scheduled examinations
(b) Special examinations for sick or disadvantaged students.
1.3.2 Continuous assessment of assignments, projects and devices, essays, quizes, other submitted work from students.
1.3.3 Marking examination papers, conducting and assessing special tests.
1.3.4 Collation, checking and reporting marks and assessments.
1.3.5 Post-examination staff meetings and student interviews.

**1.4 Management**
1.4.1 Marketing and publicity—Open days, web sites, brochures.
1.4.2 Management of Resources
(a) Teaching assistance—recruitment and payment of tutors.
(b) Facilities—maintenance and updating of computers, laboratory equipment.
(c) Accounts—monitoring and control of recurrent expenditure for teaching programmes.

**1.5 Scholarship in education**
1.5.1 Quality Assurance
(a) Reflection on current course content and presentation.
(b) Reflection on feedback from student questionnaires, staff/ student working groups and committees.
1.5.2 Authorship of Text Books
(a) Writing undergraduate text book.
(b) Negotiation with publishers.
(c) Reviewing publishers' proposals for new text books.

Note: Activities related to major innovations in engineering education and to educational R & D are classified under 'Research', Sections 3.1 and 3.2.

2. *Research and technology transfer*
Activities associated with the advancement and dissemination of knowledge in engineering and engineering-related disciplines.

**2.1 Research**
2.1.1 Devising research projects and preparing consolidated statements of aims, scope, methods.
2.1.2 Searching for funds from industry, government, foundations, venture capitalists.
2.1.3 Recruitment of researchers
(a) Masters and Ph.D candidates.
(b) Post-doctoral fellows, visiting research fellows, research engineers, technical staff.
2.1.4 Preparation and submission of research proposals including follow-up interviews and presentations.
2.1.5 Supervision of research students.
2.1.6 Management and administration of research grants and contracts
(a) Monitoring progress of research and supervising research staff
(b) Purchase of equipment and instrumentation
(c) Monitoring accounts and controlling expenditure.
2.1.7 Reporting to funding bodies on progress of research and results achieved.

**2.2 Scholarship in research**
2.2.1 Postgraduate
(a) Examination of postgraduate theses.
(b) Research seminars—organisation, delivery, participation.
2.2.2 Conferences (national and international)
(a) Writing papers
(b) Editing conference proceedings
(c) Organisation, committee work, reviewing papers
(d) Attendance and participation
(e) Keynote addresses, special roles.
2.2.3 Journals—internationally refereed journals
(a) Writing papers, responding to reviewers' comments, proof reading
(b) Reviewing papers
(c) Editorial responsibilities.
2.2.4 Books
(a) Writing books incorporating results of research
(b) Negotiating with publishers
(c) Reviewing books for journals, publishers.

**2.3 Technology transfer**
2.3.1 Engineering consultancies for industry and government
(a) Preliminary discussions, offer
(b) Investigations and report.
2.3.2 Educational consultancies—national and international.
2.3.3 Continuing education—industry-based
(a) Preliminary discussions and offer of course
(b) Preparation of course material, educational aids
(c) Delivery of course, follow up visits and discussions.
2.3.4 Continuing education—special courses for learned societies, professional bodies.
2.3.5 Patents—discussions and negotiations.

**2.4 Marketing and publicity**
2.4.1 Marketing research and technology transfer within universities, academic networks.
2.4.2 Marketing research and technology transfer to companies, media, general public.

3. *Service*
Activities associated with the collegiate working of university systems of governance and with interfaces between the University and external organisations and groups.

**3.1 Provision of service within the university**
3.1.1 Service to students—student welfare and counselling, advice on course and career planning.
3.1.2 Service to academic group in department—courses, budgets, staffing.
3.1.3 Service to department (general)—administration and committees.
3.1.4 Service to department (special)—accreditations and reviews, annual reports.
3.1.5 Service to graduates—assistance for career enhancement.

3.1.6 Service to Faculty—administration and committees.
3.1.7 Service to the University—administration and committees.

**3.2 Public service**
3.2.1 Service to other universities
(a) Advisory committees
(b) Academic reviews
(c) As visiting academic staff.
3.2.2 Service to schools—liaison and advice on university courses, professional careers.
3.2.3 Service to professional and learned societies, academies—membership of boards, councils, committees, professional advice.
3.2.4 Service to national and international discipline groups.
3.2.5 Service to national and international organisations—CSIRO, Standards Associations, Engineering Sciences Data Unit, United Nations agencies, and related bodies.
3.2.6 Service to governments and government agencies
(a) Professional advice
(b) Submissions to government and parliamentary enquiries
(c) Reviews of research proposals and grant applications.

4. *Academic infrastructure*
Activities supporting and informing engineering education, research and technology transfer.
4.1 Inviting and hosting academic visitors and exchanging ideas with them.
4.2 Reading journals and books, updating personal library, recommendations for purchases by university library and bookshop.
4.3 Academic networking.
4.4 Industry liaison—current and potential problems, issues.
4.5 Strategic and long term planning—educational and research programmes, major innovations in courses, departmental organisation.
4.6 Updating knowledge of and skills in educational technology, computer aided learning, multi-media presentation.
4.7 Updating knowledge and skills regarding ancillary matters such as occupational health and safety, intellectual property, equal opportunity, trade practices.
4.8 Maintaining personal files and records.
4.9 Personal research, reflecting on and thinking through significant academic issues and problems.

## APPENDIX 2: CRITICAL EVENTS AND KNOWLEDGE GAINED IN THAT PART OF WPL'S CAREER SHOWN IN FIG. 1

*Strand No. 1*
(1) Request for investigation of equipment failure (received by AES)
(2) Submission of report to client (by AES)
(3) Short case study written based on this investigation
(4) Enrolment of Masters candidate for research into engineering diagnostics
(5) Analysis of responses to case study by professionals and students
(6) Submission of Masters thesis
(7) Presentation of conference paper based on thesis
(8) Refereed publication—journal article, revised and extended version of conference paper

Knowledge gained: cognitive skills exercised in diagnosis of engineering failures.

*Strand No. 2*
(1), (2) and (3) as for Strand No. 1
(4) Decision to administer case study to different groups of students
(5) Analysis of students' responses to case study
(6) Completion of internal report based on this analysis
(7) Presentation of conference paper based on internal report

Knowledge gained: hierarchical representation of knowledge base for diagnosis of engineering failure.

*Strand No. 3(a)*
(1) Request for advice on design of critical component in power transmission
(2) Submission of report to client
(3) Short case study written based on this investigation

(4) Incorporation of case study into undergraduate programme in engineering design
(5) Analysis of students' responses to case study
(6) Completion of draft internal report based on this analysis
(7) Creation of networks for modelling information flows in engineering design
(8) Completion of internal report in final form, incorporating these networks
(9) Presentation of conference paper based on internal report

Knowledge gained: design information flow networks as a tool for research into and management of engineering design.

*Strand No. 3(b)*
(1) to (7) inclusive as for Strand No. 3(a)
(8) Publication of case study in ASEE Engineering Case Library

Knowledge gained: experimental data on the process of designing mechanical components.

*Strand No. 4*
(1) Personal decision to research the design of mechanical components
(2) Presentation of conference paper on role of intelligence in mechanical design
(3) Critical discussion of conference paper
(4) Refereed publication—chapter of book based on conference paper

Knowledge gained: information processing models of tasks in engineering design

*Strand No. 5*
(1) Enquiry received from potential Ph.D candidate
(2) Enrolment of Ph.D candidate for research into innovation in industry
(3) Submission of Ph.D thesis
(4) Presentation of conference paper based on thesis
(5) Submission to parliamentary enquiry on industrial innovation

Knowledge gained: characteristics of innovation in Australian manufacturing industry

*Strand No. 6*
(1) Invitation to deliver continuing education course (received by AES)
(2) Delivery of course on engineering design in a mass production industry
(3) Analysis of data provided by course participants completed
(4) Presentation of conference paper based on this analysis
(5) Refereed publication—journal article adapted from conference paper

Knowledge gained: theory and practice of quality assurance in product design and development.

*Strand No. 7*
(1) Successful completion of industry/university research project
(2) Invitation to deliver continuing education course
(3) Delivery of course on strategic product development in SME's
(4) Analysis of data provided by course participants completed

Knowledge gained: experimental data re product design and development.

*Strand No. 8*
(1) Call for papers received from organisers of international conference
(2) Offer of paper accepted by conference organisers
(3) Presentation of conference paper on concurrent engineering of product design
(4) Critical discussion of conference paper
(5) Refereed publication—journal article, extended version of conference paper

Knowledge gained: tools for management of product design and development.

*Strand No. 9*
(1) Call for paper received from organisers of international conference
(2) Offer of paper accepted by conference organisers
(3) Presentation of paper on potential failure networks in product design
(4) Critical discussion of paper in letters received from other researchers

Knowledge gained: a strategy for accelerating product design and development.

*Strand No. 10*
(1) Approach received from person interested in researching engineering design
(2) Appointment of this person as a Visiting Research Fellow (VRF)
(3) Submission of internal report on potential failure networks by VRF

Knowledge gained: application of potential failure networks to product design.

*Strand No. 11*
(1) Call for papers received from organisers of international conference
(2) Offer of paper accepted by conference organisers
(3) Presentation of conference paper on benchmarking new product development
(4) Critical discussion of conference paper
(5) Refereed publication—chapter of book based on conference paper

Knowledge gained: application of benchmarking procedures to product design and development.

*Strand No. 12*
(1) Personal decision to undertake research
(2) Offer of paper accepted by organisers of conference on engineering education
(3) Presentation of conference paper on the quality of academic life
(4) Critical discussion of conference paper
(5) Refereed publication—journal article adapted from conference paper

Knowledge gained: appreciation of some aspects of academic work in engineering.

## APPENDIX 3: STAKEHOLDERS IN ENGINEERING IN UNIVERSITIES

*(A) Direct stakeholders identified in Appendix 1*
Stakeholder and relevant Sections in Appendix 1

- Undergraduate—current (1.2, 1.3, 1.5.1, 3.1.1)
- Undergraduate—future (3.2.4)
- Postgraduate (2.1.3, 2.1.5)
- Graduate (3.1.5)
- Industry—employers of graduates (4.4 See also Part B of this Appendix)
- Industry—partners, collaborative u/g projects (4.4, 1.1.2, 1.2.1)
- Industry—technology transfer (2.3.1, 2.3.3, 2.3.5)
- Research funding bodies, including research collaborators—ARC, government agencies, foundations (2.1.2, 2.1.7)
- Research funding bodies—companies, venture capitalists (2.1.2, 2.1.7)
- Professional and learned societies, technical agencies (2.2, 2.3.4, 3.1.4, 3.2.2, 3.2.3)
- Academic discipline networks, communities of scholars (4.1, 4.3, 1.5.2, 2.1.8, 2.2.2, 2.2.3, 2.2.4, 2.3.2, 2.4.1, 3.2.1,)
- Government agencies, departments (3.2.5)

*(B) Stakeholders in industry*
Destinations of graduates in mechanical and manufacturing engineering, University of Melbourne

**Primary industry:**
- Agricultural machinery
- Mining and Minerals Processing
  —operations and maintenance,
  —mining and minerals processing machinery

**Manufacturing industry:**
- Continuous Processing
  —chemicals, plastics, oil exploration and refining, petrochemicals
  —steel, aluminum, other metals
  —power generation
- Discrete products
  —automotive vehicles and components
  —tools and appliances
  —transport—rail, aerospace
  —transport vehicles and systems

—scientific and medical instruments
—niche products
—general manufacturing

**Service industry:**
- Consulting
  —Engineering
  —Management
  —Computing and information systems
  —Education
- Banking and Finance

**R&D, knowledge-based industry**
- R&D laboratories in large corporations, government agencies CSIRO, universities
- Product design and development companies
- Patent attorneys

## APPENDIX 4: BENCHMARKING ACADEMIA

Items used to evaluate the performance of the authors' engineering department, University of Melbourne, 1995

Note: These evaluations supported an extensive programme of interviews with students, staff, recent graduates, graduates in established careers, university and industry leaders.

*Undergraduate*
- Tertiary entrance rankings of students entering engineering course, based on results obtained in high school certificate of education examinations, taken as indicator of entry standards.
- Course reviews and innovations in the past 5 years.
- Diversity of course options offered to students.
- Numbers of undergraduates in each Year of course, trends over past 5 years.
- Numbers of graduates produced per annum for the past 5 years.
- Proportion of entering students (a) graduating in minimum time, (b) graduating in minimum time plus one year, (c) discontinuing course.
- Student evaluations of teaching, rankings on scale of 1 to 5, comparisons with engineering departments at other Australian universities.
- Employment of new graduates—percentage finding employment within six months of final examinations, comparisons with other Australian universities.

*Postgraduate*
- Numbers of postgraduates, Masters and Ph.D's over past 5 years, comparisons with other Australian universities.
- Ratios of numbers of postgraduates to undergraduates over past 5 years, comparisons with other Australian universities.
- Completion rates, proportion in minimum time.
- Numbers of postgraduates holding scholarships awarded on basis of high academic merit.

*Scholarship*
- Distinctions held by academic staff—awards of prizes, medals, elections to learned academies, taken as evidence of quality of staff.
- Editorial assistance and review of papers—list of international engineering journals.
- Organisational work for national and international conferences—list of conferences.
- Academic visitors to department—list of names, durations of stay.
- Membership at senior level of learned societies—list of relevant academic staff and societies.

*Publications*
- Total number of papers published in international refereed journals in past year, list of journals containing these publications.
- Number of journal articles per annum per member of staff, comparisons with similar data for other Australian universities and leading universities in U.S.A., U.K., Japan, S.E. Asia.
- Weighted annual publication index for past 10 years for department as a whole, comparison with other engineering departments at the University of Melbourne.

- Weighted annual publication index per member of staff, comparisons with other Australian universities and leading universities in U.S.A., U.K., Japan, S.E. Asia.
- Number of refereed papers presented at international conferences, list of conferences.

*Patents*
- List of patents and academic staff responsible for them.

*Technology transfer*
- Continuing education courses presented, list of those conducted in previous 12 months.
- Consultancies, list of clients and matters investigated for them.

*Research—basic and strategic research funded by the Australian Research Council (ARC)*
- List of ARC grants for 1995, project titles.
- Research funding received from the ARC, each year for the past 5 years, comparisons with other Australian universities.
- Research funding received from the ARC per member of staff, comparisons with other Australian universities.

*Sponsored research*
- List of projects and contracts.
- Total annual funds received for sponsored research for each of the past 3 years, trends.

*Public service*
- Review of research grant applications.
- Assistance to government departments and agencies in Australia.
- Service to other universities, CSIRO.
- Service to national standards associations and learned societies.
- Service to international standards associations and learned societies.

**Dr W. P. Lewis, ME, PhD**, founded the Engineering Design Group in the Department of Mechanical and Manufacturing Engineering, University of Melbourne. Together with colleagues in the Group he has established a coherent, structured undergraduate programme in engineering design at Melbourne. In his work at the professional level Dr Lewis has conducted continuing education courses in Strategic Product Development and has contributed to courses on Engineering Design for Mass Production. His research and consultancy interests include engineering education, innovation and public policy, design theory and methods, quality assurance and design project management. He is the author or co-author of two books and more than forty papers in these fields.

**J. G. Weir, BE**, has been a member of the Engineering Design Group at the University of Melbourne since 1987. Prior to that he worked for ICI Australia as a design engineer and project engineer, specialising in process equipment and control systems. His research interests are in the areas of design for the environment and computer-augmented design, with particular emphasis on 3-D modelling and visualisation. Mr Weir is active in developing computer-based simulations and concept maps as aids to student learning. Since 1994 he has conducted three major educational research projects for developing novel software to promote learning in designing for product integrity.