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AUTHOR Stevens, Susan A. R.; Wilkins, Linda C.
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ABSTRACT

Engineering is the science, art, and business of designing and getting things done; engineers are required to make things happen through interpersonal relationships. At Monash University (Australia), a new course, Management for Engineers, was set up in 1990 to encourage a more holistic approach to the process of engineering. The course included an examination of the context within which the end product is based. The techniques of problem based learning (PBL) were used to look at design as a problem solving activity for engineers. This report provides the outline for an engineering course that includes communication skills as a deliberate part of the design and places a strong emphasis on process and interaction. The style of the course delivery means, in practice, fewer lectures, more tutorials, and the use of cross cultural models to modify activities that would be appropriate for the group. Awareness of the specific culture and language of the engineering profession was given increasing attention throughout the course. Course orientation transfers the initiative from the lecturer to the student and immerses students in an environment that challenges them to think and to take responsibility for identifying and learning skills. (Contains 25 references.) (LL)

ENGINEERS:

DESIGNERS – NO ALIBIS

National Biennial Conference
of the
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Susan A R Stevens
School of Graduate Studies
Monash University

Linda C Wilkins
Faculty of Engineering
Monash University

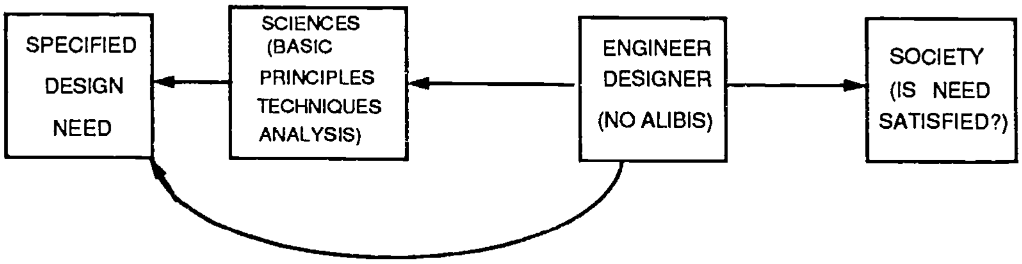
ENGINEERS: DESIGNERS - NO ALIBIS

ABSTRACT

Engineering is the science, art and business of designing and getting things done. At Monash University, a new course, Management for Engineers, was set up in 1990 to encourage a more holistic approach to the process of engineering. This included an examination of the context within which the engineer functions as a professional. There was a focus on the relationship and responsibility the engineer has for the context within which the end product is located. The techniques of problem based learning (PBL) were used to look at design as a problem solving activity for engineers.

ENGINEERS: DESIGNERS – NO ALIBIS

NATURE OF DESIGN Application of a constructive imagination to a known body of knowledge. An Art rather than a Science i.e. design is a science made effective by skill. An act of creation and not of analysis. An infinite range of design solutions are usually possible because the number of variables >> number of design equations. Must seek optimum solution, having decided on the basis of optimisation.



(Bonwick, 1993)

In 1588, the word design had the meaning "purpose, aim, intention". By 1657, the meaning had become "the thing aimed at". In the 20th century, design has gained the composite meaning of aim plus thing aimed at (Bertram, 1938). It has come to stand for a process – from the original concept through the plan and the manufacture to the finished object. It encompasses the purpose, the method and the material used to construct the object.

Engineers have added further dimensions to the idea of process as a definition of design. Henry Petroski, a civil engineer and author of a number of textbooks on engineering design, has described the evolution of a design as the successive elimination of faults and errors (Petroski, 1992). Others, particularly in the area of industrial design, look for "a balance between the more organic, softer image of a lovingly fashioned product and the excitement that is associated with cutting edge technology" (Medd, 1993).

In 1990, the authors of this paper were faced with the challenge of designing a course in management for undergraduate students in Monash University's Department of Electrical and Computer Systems Engineering (DECSE). The brief was to give the students a broad introduction to "management', including development of communications and human relations skills and an understanding of the location of the engineer in society.

As instructional designers, in creating this course we felt it to be important to assess how principles of design were articulated by the engineers we were to work with. DECSE includes electronics, digital, power engineering, telecommunications and control engineering among the major areas taught. So we sought examples of their approach to design from those streams.

Lecture notes from the field of power engineering indicate that here, design is seen as a matter of perspective, of balancing conflicting demands. The key issues, as outlined in a design for a turbo generator are:

* achieving the specification,
* achieving quality, reliability and availability,
* ability to sell at a competitive price,
* adequate allowance for simple maintenance procedures.

The importance of reliability – "reasonable balance between conflicting demands of minimum cost, maximum efficiency, maximum reliability and maximum availability" – is particularly emphasised (Bonwick, op cit).

For electronic engineers, a major design priority is control of complex specifications produced by the customer. The following, from a preface to a text book co-authored by a member of DECSE, exemplifies this conception of design:

> "the part of amplifier design that is essentially engineering is in making approximations. When an analytical expression becomes too unwieldy for convenience, it is not enough just to neglect high order terms: it is necessary to determine what constraints should be placed on the system or what design rules would be observed to ensure that these terms are in fact small. Engineering has aptly been described as 'the art of making approximations'." (Cherry & Hooper, 1968).

Problems of precision, reliability and reproducibility that engineers face can be reduced to a single requirement – i.e. "designability" (Williams, 1946). Electronics engineers apply this principle to the development of circuits "whose operation can be predicted accurately before they are built" (Cherry and Hooper, op cit).

Designing circuits or digital technology introduces another concept – that of "testability":

> "If the particular design style adopted to ease the testing problem is to be accepted by the design community it must be easy to apply and not so constraining as to inhibit the ingenuity of the designer" (Russell et al, 1985)

The design of integrated circuits involves complexities where there is a constant trade-off between compactness, and the possibility of testing and modifying that design at a later date.

Predicting accurate outcomes, achieving reliability and testability are related to a third feature inherent in successful engineering design - team management. "The success of the design offices of industry rests on the ability to manage teams engaged in this process ' (Norris, 1983).

The outline of what design means to engineers in different specialisations feeds into instructional design in the management course for undergraduate engineers. Informing the whole three units is a deliberate emphasis on extending the student's appreciation of what defines their specialty eg. design and its application to management situations.

Establishing principles of design in engineering leads us to consider the engineer's persona. What is an engineer? Design, in some significant ways, serves to define the profession both by what it lays claim to, and what it does not.

An engineer is more than a technician because s/he, unlike the technician, goes beyond a life of mechanical repetition and exhibits:

* a willingness to attack a situation never seen or studied before and for which data are incomplete,
* an acceptance of full responsibility for solving the problems on a professional basis (after Cherry and Hooper, op cit).

Again, the engineer's work differs from that of the scientist in a number of ways that impinge upon design. Where the scientist isolates and defines distinct concepts, the engineer seeks to integrate and synthesise data and designs. Whereas the goal of science is the pursuit of knowledge and understanding for its own sake, the goal of engineering is the creation of successful artefacts and systems to meet people's wants and needs (see Table 1 below).

TABLE I

SOME DIFFERENCES BETWEEN SCIENCE AND ENGINEERING

SCIENCE (*Goal*: the pursuit of knowledge and understanding for its own sake)	ENGINEERING (*Goal*: the creation of successful artefacts and systems to meet people's wants and needs.)
<u>Key scientific processes</u>	<u>Corresponding engineering processes</u>
Discovery (mainly by controlled experimentation).	Invention, design, production.
Analysis, generalisation and synthesis of hypotheses.	Analysis and synthesis of designs.
Reductionism, involving the isolation and definition of distinct concepts.	Holism, involving the integration of many competing demands, theories, data and ideas.
Making more or less value-free statements.	Activities always value-laden.
The search for, and theorising about, *causes*, (eg gravity, electromagnetism).	The search for, and theorising about , *processes*, (eg control, information, networking).
Pursuit of accuracy in modelling	Pursuit of sufficient accuracy in modelling to achieve success.
Drawing correct *conclusions* based on good theories and accurate data.	Reaching good *decisions* based on incomplete data and approximate models.
Experimental and logical skills.	Design, construction, test, planning, quality, assurance, problem-solving, decision-making, interpersonal, communication skills.
Using predictions that turn out to be incorrect to falsify (sic) or improve the theories or data on which they were based.	Trying to ensure, by subsequent action, that even poor decisions turn out to be successful.

(Sparkes, 1989)

Engineering deals constantly with situations for which data is incomplete, and therefore must deal with uncertainty. Unlike the scientist, whose work is drawing correct conclusions based on good theories and accurate data, the engineer must deal with competing demands, quality assurance, human relations demands by the nature of his/her work. In sum, engineering is context dependent to a degree unacceptable in science.

> "The engineer, like the scientist, is concerned that the solution of his problem shall be sound and logical, but unlike the scientist, he is also concerned with the requirements of customers and society, some reasonable and relevant, some otherwise, with optimum economy and efficiency and with the interrelationship of many problems of employer and employed" (Melling, I.E.E., 1989).

The engineer may, in this context, be defined as a problem solver. Her/his identification of the problem " must be made in response to a need, in the face of considerable uncertainty and gaps in knowledge" (IEAust, 1990). Faced with incomplete access to the facts the engineer who takes on a management role finds that as leader s/he has to have a capacity to make organisations and tasks appear comprehensible and coherent to others and the ability to make things happen through inter-personal relationships.

In the light of these required attributes, the instructional designer needs to be aware of the personal and professional profiles of engineers, the weaknesses and strengths that have been identified as typical:

* low interest in persuasive activities and activities directed towards personal involvement with other people,
* lack of human insight, tact and easy human skills,
* over-preoccupation with detail; lack of breadth of perspective,
* decisive, methodically persistent, driven to achieve.
* high interest in scientific and mechanical things,
* high aptitude in spatial perception,
* high aptitude for mechanical comprehension,
* high on abstract and numerical reasoning.

(Lloyd, 1979).

In addition, surveys of employers of engineers have identified the skills that they seek in recent graduates, which are basically human relations and communications skills.:

* effective communication with others,
* ability to work co-operatively at all levels,
* ability to be part of a team.

(Hessami and Eley, 1992).

Others have identified problems in the way engineers are taught that accentuate their negative aspects or weaknesses and inhibits them from reaching the ideal of the engineer:

> "Engineering courses are overloaded with facts and details of specific disciplines, with emphasis on logical and serial thinking. There is no time to reflect and extract the underlying lessons and to look at the total picture, reducing the effectiveness of the graduate engineer...[There is a] need to change teaching methods and change the patterns of thinking encouraged...For innovation [we] need to call engineer's attention to the range of factors involved in the process of innovation rather than the detailed design of particular systems...[We] need to alert engineers to [the] importance of qualitative, intuitive, creative, non technical aspects of innovation." (Symons, 1989).

McGregor and Johnston identify the issues that should be addressed at the commencement of a student's professional studies in order to, provide an appropriate context for further engineering education:

* a commitment to lifelong learning,
* an appreciation of the full scope of professional practice,
* an improvement in communication skills.

(McGregor and Johnston, 1992).

This, then, is what the authors, in their design of a three semester course in management skills for undergraduate engineers set out to do – develop the strong attributes, and compensate for the negatives, within a context which broadens the scope of how engineers identify themselves and their roles. In terms of design, this meant alerting engineers to their role within the community as the interpreters, and arbiters, of, not only technically sound, but also environmentally, socially, and ethically acceptable, propositions – for roads, buildings, modern artefacts, etc. It also meant that at least as much attention was paid to the implementation – the processes – of the course as to its formal content.

Few undergraduate, engineering courses include a consideration of the role of the engineer as a professional. Indeed, in Australia, there has been little research in this area at all.

Brian Lloyd has traced the history of the development of engineering in Australia as a profession, as opposed to a technical occupation (Lloyd, 1991). But possibly only Anderson, in Australia, has considered the nature of the professional role of engineers.

In a longitudinal study reported in Australian Educational Research (Vol. 18, No. 1, 1991), Anderson describes the four critical intelligences for a professional (engineer, doctor, lawyer, teacher). These are:

* a technical intelligence,
* a critical intelligence,
* a civic intelligence,
* the development of the professional as teacher.

(Anderson, 1991).

The development of a technical intelligence – " the application of scientific thinking to the solution of practical problems" – is, Anderson argues, what Australian universities achieve well. When that is considered in light of our definitions of the nature and process of design, it is clear that a merely "technical" intelligence will reduce "design" to a function of the object, rather than the object being an outcome of the process of design. Thus, although it is a step in the process providing neat-fit solutions will not, on its own, produce adequate or acceptable design.

The "critical" intelligence is one that is more concerned with ends. Following Anderson's typology, the critical intelligence does not always sit easily with the technical intelligence. Whereas the technical intelligence is about how to get from A to B, the critical intelligence looks for alternatives, and even questions whether B is worth getting to. For the professional engineer, this is closer to Petroski's statement that "engineering is not about absolutes" (Petroski, op cit).

The "civic" intelligence develops this further. A civic intelligence locates the professional in society – in its history, literature, politics and sociology. It posits a sense of public identity and responsibility. This is a difficult concept for any profession - located and educated as most of its members are within the culture of that profession, rather than that of the broader community. The focus of this conference is that of design transcending narrowly defined professional or technical areas: the focus of our course has been to widen the horizons of one professional/technical group so that they are not "exclusive". Herein lies the importance of developing a civic intelligence.

The fourth "intelligence" that Anderson identified is that of the professional as teacher. In terms of the time given for the course each week (three hours), this was necessarily a subsidiary focus. The encouragement of work teams within the larger groups, and of pairwork to help develop some of the practical assignments, did reflect this part of the professional's role.

It has already been emphasised that, in developing the DECSE course Management for Engineers, the authors were concerned to work from within the perspective of the engineer. To this end, course materials and exercises were developed that were based on existing materials in the department; existing staff members were drawn into the course as tutors, guest lecturers and information resources; and research about what an engineer is, and how they are perceived, was used.

The course, in its final outline, is shown in Table II. The concentration on communication skills is a deliberate part of the design. Engineering educators need to be aware that "Engineers will spend much of their professional lives communicating their ideas to others, and the sooner we start the development of those the better. Standard lectures and tutorials do not provoke this type of discussions and argument" (Hadgraft, 1992).

Implementation and delivery of this course were integrated, with a strong emphasis on process and interaction. The following were considered critical for successful implementation:

* size of the group
* resourcing
* intra-departmental relationships
* staffing
* course orientation
* learning principles
* assessment procedures

These have been discussed in detail in previous papers (e.g. Stevens and Wilkins, 1993).

Delivery of the course was also differentiated from other engineering subjects with a focus on the language needs of engineering students. The approach here was not the traditional one, where content and linguistic expression are seen as two independent elements. "The problems of linguistic expression are already problems of understanding" (Gadamer, 1975). Accepting this responsibility in course design has implications for teaching style.

An emphasis on the style of delivery of the course meant, in practice, fewer lectures more tutorials, and the use of cross cultural models to modify activities appropriately for the group.

Process and the audience were emphasised both in tutorials, which made up the majority of formal teaching time, and in assessment.

Awareness of the specific culture and language of the engineering profession was given increasing emphasis throughout the course. A variety of teaching styles and instructional design models were needed to address directly the communicative competency needs of all engineering students (Wilkins and Wellings, 1992)

Table II – Course Outline

1: Unit Outline for Communication

Theme	Session Topic	Coverage
A. Oral Communication	1. Professionals as Managers 2. Oral Communication 1 3. Oral Communication 2	Potential for Managers Interpersonal, Intrapersonal Listening, Non-Verbal
B. Communication in Group	4. Small Group Communication 5. Large Group Presentation 6. Organisational Communication 7. Negotiation	Relationships, Roles Preparation, Presentation, Feedback Organisations, Taylor, Hawthorne Studies Negotiating Skills, Preparation, Win-Win
C. Written Communication	8. Written Communication 1 9. Written Communication 2 10. Reading Skills	Memoranda, Letters Reports Reading Skills
D. General	11. Communication as a Management Tool 12. Review Session	Organisations as People, Source/Receiver Course Issues, Course Feedback

2: Unit Outline for Managing Resources

Theme	Session Topic	Coverage
A. Managing People	1. The Individual 2. Organisations & Groups 3. Management Intro 1: Philosophy 4. Management Intro 2: Techniques	Motivation, Attitudes, Abilities Group Dynamics, Hawthorne Studies Management "Thought", Leadership Management "Reality", Meetings & Time
B. Managing Finance	5. Projects & Enterprises 6. Accounting Fundamentals 7. Financial Planning & Control 8. Project Evaluation	Company Objectives, Financial Statements Principles, Cash/Actual Accounting Planning Budgeting Time Value of Money
C. Managing Projects	9. Managing Projects 10. Critical Path Methods 11. Law	Project Teams, Project Planning Networks, Gannt Chart, Resources Contracts
D. General	12. Review Session	Course Issues, Course Feedback

3: Unit Outline for Marketing & Business Planning

Theme	Session Topic	Coverage
A. Marketing	1. The Customer 2. Business Management 3. Strategic Marketing 4. The Marketing Mix 5. Quality Management 6. The Business Plan	Needs & Wants, Marketing & Selling Company Purpose, Growth Strategies Marketing Opportunities, Marking Plan Product, Price, Place, Promotion Western Tradition, Variation, Quality Reviews Planning Process, SWOT Analysis
B. Public Sector Business	7. Government Business 1: 8. Government Business 2:	Government Role & Size, The Budget, Case Study
C. Law	9. Law 1: 10. Law 2:	Environment, Employee Product Liability, Expert Witness
D. General	11. The Engineering Role 12. Review Session	Professional Role, Ethics Course Issues, Course Feedback

The premise in the course design is that there is a fundamental relationship between effective communication and awareness of the processes involved in co-operative undertakings. Management for Engineers is a course envisaged as continually evolving through interactive processes. Our particular focus is on the interpersonal activities that characterise the tutorial/workshops. The intention was to initiate a joint learning process for both students and staff, based on small group activities. Compared to traditional engineering subjects, it is resource intensive in contact time, personnel and facilities. The difference in approach has been noted and generally approved by students. Being neither didactic nor prescriptive, the DECSE course has acted as catalyst for change in the approach of other engineering staff to their teaching, and for the students to question the style of learning expected from them. In some ways, this has begun the shift for future graduate engineers to approximate more closely the ideal engineer/designer discussed at the beginning of this paper.

One of the important techniques for this has been the use of problem based learning (PBL). Common to both the philosophy of the DECSE course and PBL is the emphasis on transferring the initiative from the lecturer to the student, and immersing students in an environment that challenges them to think and to take responsibility for identifying and learning skills. The key features shared by PBL and Management for Engineers are set out in Table III.

TABLE III

COURSE ORIENTATION
PROBLEM BASED LEARNING CONCEPTS

Course Orientation	Learning Skills
1. ☐ Less talking at students ie. fewer lectures and more talking with the students ie. more tutorials	1. ☐ Digesting a large amount of reading material
2. ☐ Challenging open-ended projects	2. ☐ Identifying the problem
3. ☐ A resource oriented teaching environment	3. ☐ Communicating effectively with students from other cultures and other disciplines
4. ☐ A focus on skills rather than on memorising material	4. ☐ Negotiating a settlement that is agreeable for all
5. ☐ Lecture notes and other resources treated as a context but not as a focus for the course	5. ☐ Recognition of the difficulties of deriving a "best solution" when there are many intangible and unquantifiable factors involved

This re-orientation in the teaching of engineers returns to the idea behind the title of this paper. A number of undergraduate engineering courses are now coming to terms with the need to engender a different outlook or orientation in their students (e.g. Choi and Pudlowski, 1992; Duggan, 1992). The objectives outlined in Duggan's paper on the teaching of environmental issues to engineers are relevant here:

* to understand issues in terms of their impact at global, regional and local levels,
* to select appropriate engineering solutions to problems,
* to appreciate the socio-economic infrastructure within which problems must be treated.
* to propose and implement sound engineering solutions to safeguard the future,
* to develop the ability to contribute positively to debate on issues.

(Duggan, op cit)

The Management for Engineers course that the authors designed for DECSE invites students to participate in such concerns. In doing so, it returns us to a consideration of the definitions of design presented at the beginning of this paper. Developing heightened consciousness of the outcomes of engineering practices in terms of the end uses, results or consequences of those practices, leads to a stimulation of interest in good design. Locating the professional engineer within society leads to consideration of what the products of engineering are and how they relate to the community. That is the responsibility of instructional designers and the challenge for university faculties. It makes little sense to work with students on their skills and approaches to their profession if the lecturers and departments do not change. Philip Candy noted in another context, "there are severe limitations as to how much the teaching/learning transaction can be modified if the institutional culture remains unaffected. This insight has particular significance for policy makers and administrators as well as to educational developers." (Candy, 1993).

Don Watts, in his opening address to this conference, referred to the traditional culture of university education and contrasted it with the style of education he would like to see in Australian universities.

TABLE IV

TRADITIONAL	PROPOSED
single discipline	interdisciplinary
theory and concept	practical
inward looking	risk and experimentation
analytical	synthesising
"clients" are the peer group	"clients" are students and/or those outside the university setting

(after Watts, 1993, DECA Conference)

He advocated that universities empower students to learn to question, to use their imagination to illuminate facts. This is where the designers of the DECSE course began. Seeing what needs to be questioned in order to ask pertinent questions – threatens established traditional ways of seeing and doing in institutional cultures. For those of us who accept the premise that education starts with questioning it must follow that the **nature** of that questioning then becomes problematic.

It is here that the designers of the course, Management for Engineers attempted to straddle the long-standing divide between two traditions of enquiry, two perspectives. In the soft system which encompasses belles lettres or the humanities there is a tradition that speaks of issues and accommodations rather than problems and solutions. The soft system contests claims to a knowable reality; when problems are formulated those speaking from the "soft" tradition question the formulation and ask whose is the problem, whose the perspective taken.

Common to disciplines such as systems engineering and operations research in the "hard" tradition, we find problem "identification" is common terminology suggesting the problem is independent of the process of its formulation. The question of who defines the issue as a problem is ignored. Implicit is the assumption that, once the problem is identified, a solution exists/is possible. In this tradition there is a concentration on outcomes based on a knowable reality. (See Table V).

TABLE V

Two Perspectives

Soft system	Hard System
☐ speaks of issues, accommodations	☐ speaks of problems, solutions
☐ concentrates on problem formulation	☐ concentrates on problem identification
☐ questions whose problem whose formulation	☐ concentrates on outcomes assumes solution exists

(after Checkland and Scholes, 1990).

How does one reconcile such divergent systems? The stated aim of this conference is to present design as an interface for such a reconciliation between a range of disciplines. Working from a recognition of the existence of general or universal laws the engineer acknowledges that "at almost all levels of design, the designer must be aware of the conflict existing between standard practice and creativity" (Cherry and Hooper 1968). This necessary and fundamental tension reiterates the engineer's constant challenge to conceive the new from the old in which diverse parts of the "given world" of the scientist and the "made world" of the engineer are reformed and assembled into something the likes of which Nature has not dreamed..." (Petroski 1992). Learning to ask questions and learning to see what needs to be questioned is only another way of describing that idea of honesty so fundamental to good design and the well designed object (Bertram, 1938). It is in this sense that the engineer and the course designer do not have (and do not need) an alibi.

TABLE VI

Design

=

learning to ask questions
learning to see what needs to be questioned

↓

no alibis

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