'Modelling of the Curriculum within Engineering Design Education'

by

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This work is dedicated to
the memory of my mother,

Seetha Lakshmi
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Abstract

Grounded in the belief that design is the raison d'être of academic courses in engineering, this research was carried out to produce a model curriculum for engineering design education. Skills derived from a paradigm of an engineering professional provided the base and the directions in the metamorphosis of this curriculum.

The paradigm evolved through the concatenation and analysis of the results of a review of the literature on engineering design education, a survey of practicing professional engineers and student engineers' perceptions of a professional engineer obtained through concept mapping exercises.

Core Knowledge Competence, Problem solving, Critical Thinking, Creativity, and Engineering Judgement were determined to be the primary cognitive skills required in an engineering designer. Social and Interpersonal skills were identified as significant in the effective practice of the professional engineer.

An interlinking skills matrix model was developed. Propositions relating the elements in the model were formulated and refined as a precursor to defining curriculum objectives. Competence and proficiency attainments were prescribed on three levels of increasing complexity to match the duration of current engineering programmes and the learner's need to progress sequentially.

Each of the identified skills for technical and social competence was researched for theoretical and empirical evidence to establish learning strategies that could be included in the curriculum.
An existing curriculum for a first year Engineering Design course in an honours degree programme was modified with objectives and learning strategies developed in this research to illustrate the process.

Finally, areas that could be further researched are suggested. Recommendations are made for tertiary institutions to introduce competency based curricula in their future designs and revisions of engineering courses.
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Chapter 1
Overview

The primary purpose of this research was to produce a curriculum model that is applicable in the development of a course in engineering design.

The first stage in this work involved the production of a paradigm of a professional engineer through literature research, a survey of practicing engineers and an input from senior undergraduate students of an engineering school. This resulted in an integrated skills model.

Second, the linking together of the skills and attributes elements in the paradigm, their interactions, the identification of suitable educational strategies, and the theoretical underpinnings of curricula generated a curriculum model.

Finally, a sample curriculum was developed corresponding to the already defined objectives and the proficiency levels expected of the learner with details of appropriate educational strategies identified in the literature research.

Introduction

Technology is an essential component in the generation of wealth and economic growth. Engineering is the science and art of applying technology to achieve this growth. Engineering design is the context in which the science and art of engineering can be applied. Because engineering design is the principal and co-ordinating influence in any engineering enterprise it follows that the capstone and raison d'être of virtually every engineering curriculum in tertiary education is design [Muster, 1984; Finniston, 1980; Carter, 1984].

Unlike the other core subject areas of the discipline, engineering
design cannot be melted down and purified into a traditional syllabus format to be taught [SEED, 1985; Muster, 1984; Cross, 1982; Black, 1976]. Various approaches have been tried and continue to be suggested [Ashcroft, 1968; SEED, 1985; Black, 1982; Gill, 1982; Brichta, 1984] for the teaching of design. Given that there is a definite demand from industry for the tertiary institutions to develop in undergraduates certain design abilities [Carey, 1979; SERC, p3, 1985; Caulkin, 1979; Fletcher, 1986; Kimber, 1972; Smith, 1986], the burden of responsibility to provide this manpower rests with the engineering education profession.

**Statement of the Problem**

The engineering profession, like all professions, serves a vital function in society. By definition all professions base their practice on a specialised body of knowledge, organised into various disciplines, and guided by altruism. While each profession has its uniqueness they all share common dilemmas of the twentieth century. The knowledge explosion, specialisation, liberal education, and theory versus practice have all been openly discussed in education in general.

Curriculum for engineering education, however, has been for nearly 200 years, based on the teaching of well defined individual subjects. In recent years the definitive corpus of knowledge contained in these and the newer disciplines has been expanding exponentially. Therefore the 'core knowledge' approach to developing curricula in engineering education is no longer acceptable today.

It is also clear that career patterns are changing and engineers need to acquire and develop new skills during their working lives [Harrisburger, p4, 1976]. While a career in the engineering profession will depend sine
qua non on this 'core knowledge' it is the application and assimilation of new knowledge that will dictate the individual's career pattern. The curriculum for an engineering course must reflect and emphasise this requirement [Finniston, 1980, Ch4, p77].

The design of such a curriculum is of paramount importance if technology is to be applied successfully in generating a nation's wealth. Many, if not all of the objectives implicit in the above can be achieved within the environment of teaching/learning of engineering design [Wilde, 1983; Harrisburger, 1976].

The espoused aims of engineering courses are to develop the necessary attributes needed in the profession but the amount and type of knowledge and the relative importance attached to different skills and attitudes vary significantly among institutions and to a greater degree among nations [Grayson, 1977, p17-55]. This diversity begs the question - 'what should an engineer know in order to be classified as a professional engineer?'. It is arguable that there is no easy or universal solution to such a question. It is almost an affront to the imagination to make sense or get a consensus from the numerous courses offered by institution all over the world - all in the name of education of the mechanical engineer!

Some findings on the study of the neglected field of curriculum design and evaluation [Wood & Davis 1978] have highlighted the following aspects:

1. Most curriculum change is piecemeal, incremental and unplanned with respect to the total curriculum.

2. For curriculum development work to be taken up there needs to be some sense of dissatisfaction with the existing curriculum.

3. The task is complex and difficult.

4. It requires someone among faculty to
exercise leadership: to gain consensus about the need for a new curriculum; to select task forces or committees to seek released time and funding; to ensure implementation; to generally take charge of the responsibility for solving problems as they occur.

5. It takes many years to accomplish a curriculum change. Five to six years is not uncommon.

6. It is a costly venture both in terms of faculty time and institutional resources.

It is, however, obvious from the numerous papers published in the recent past [Carey, 1979; Fletcher, 1986; Jones, 1986; McCormick, 1985; Penny, 1981; Roith, 1986; Sheldon, 1984; White, 1983 to quote a few] that educators and employers with vision are conscious of the need for a continued growth and development in engineering education. The task of the educator is to understand the forces and trends at work in reviewing courses so that changes come about at the right time and in the right direction.

While predictions have undertones of futility it would be foolish not to examine carefully the trends in engineering education and to ignore the opinions of educators, practicing engineers and employers regarding the needs and requirements of the future. These could form the basis for establishing practical guidelines towards an acceptable curriculum. It has been established that the society's needs in the decades ahead will call for engineering skills on a scale hitherto not experienced. Effort must be made to predict these now.

As stated earlier, design is the raison d'etre of virtually every undergraduate engineering curriculum. All engineering problems eventually trace back to the design stage for an acceptable solutions.

Therefore, a firm foundation in engineering design must be a criteria
for any programme that lays claims to being the curriculum of the future for the education of engineers.

Teaching such a subject area has to be based on a curriculum developed from insight into the activity of design as both an academic subject and a marketable skill. Therefore what and how we teach and how the students learn are vital issues that need to be resolved now.

But too often curriculum change in engineering courses have been directly as a result of pressures from professional bodies and studies [e.g. Finniston, 1980] which highlight professional competencies.

The work described here does not negate the importance and indeed the necessity of the input from these. It is, however, based on the belief that schools offering courses for the engineering profession should first address themselves to the individuals - the undergraduates - they are preparing as practitioners; to look within the individual as the means of ensuring effectiveness; to identify the skills that are perceived to be necessary to be a design practitioner and then preparing course structure and details to enhance the development of these skills.

This research, though essentially a study in mechanical engineering curriculum design, has the following purposes:

a) elicit empirical evidence from the professional practitioner, academics and undergraduate students to support and refine a theoretical paradigm of engineering practice;

b) propose a curriculum model for engineering design education using a) and theoretical underpinnings of curriculum;

c) using b) produce an engineering design curriculum that sets out to develop professional skills in engineering undergraduates.

Finally, recommendations are made for individual institutions to
pursue refinements of their own curricula and to adapt the model to their needs and circumstances.

**Nature of this research work**

1. **Need for this research**

   A professional practitioner in any field of activity can be effective only if he is trained in the skills of his profession. This research addresses the education of engineering designers from this perspective - the competencies needed (Chapters 4, 5 and 6) to enter and progress in the profession.

   The need for this research work is established through a study of engineering education in general and a probe into the immediate history and development of engineering design education in some selected environments. Current issues and trends in this field are surveyed (Chapter 2) to seek directions for the future.

2. **Engineering Design: Definitions**

   'Design' is a fashionable expression with varying implications and many prefixes - dress or fashion design, architectural design, wall paper design, furniture design, product design, engineering design etc. In terms of engineered artefacts some describe the external aspects of a system as design and the internal workings as 'engineering'. Engineers themselves refer to design as relating to the mechanisms and systems and in some simple cases to the stressing.

   A literature survey indicates quite clearly that there is no universally accepted single definition of engineering design. Perhaps as many definitions exist as there are practitioners. One that epitomises the engineering aspect of design activity is:
'Anyway you say it, engineering is man's effort to control and utilize nature for his own benefit' [Harrisburger, 1976, p1]

The word 'design' has many connotations. The thesaurus gives almost 50 alternatives or synonyms interpreting 'design' as a verb and as a noun. In providing synonyms for the 'designer', however, there are only 6 offered. These are:

artificer, creator, deviser, inventor, originator and stylist. [Collins, 1987]

The English language dictionary meaning of this word would be more suitable in describing an engineering draughtsman rather than an engineering designer. It states, in part:

'design/ n. preliminary outline or drawing for something to be made; established form of a product' [Oxford Dictionary, 1987]

Design practitioners and educators define design in a broader framework of utilisation of scientific knowledge in solving human problems. Relating to this view some very descriptive and clear definitions are:

'Design is considered as the process of selectively applying the total spectrum of science and technology to the attainment of an end result which serves a valuable purpose' [McCrorly, 1966]

'Engineering design is the creation of plans for machines, structures, systems, or processes to perform desired functions' [Hall, 1961, p1]

'Engineering design is the use of scientific principles, technical information and imagination in the definition of a mechanical structure, machine or system to perform pre-specified functions with maximum economy and efficiency' [Fielden, 1963]

Some definitions which are more philosophical and, while somewhat abstract, they do give some insight into designers' activities.

'Design... a visual or tactile shape; a plan or conceptual creation; the end product (of such a
plan; the purpose, the intention or the motivation (of the planner); the governing or controlling of process (of cybernetic exploration); a symbol or a set of symbolic representation.

[Jones, p295, 1966]

'The engineering process of innovation, design and decision making have much in common with problem solving (p516) ...So the design job is specific but not special (p517) [Heywood, p516/517, 1981]

'...the imaginative jump from present facts to future possibilities.'

'...use the maximum powers of creativity, judgement, technical perception, economic awareness and analytical logic to device uniquely useful systems, devices and processes.' [McCrory, p11, 1966]

'...initiate change in man made things.' [Jones, p4, 1970]

A group of educators who have formed an association to share their experiences in teaching engineering design [SEED] have judged that there is no single conclusive definition of engineering design and agreed that:

'The purpose of design was to meet human needs in terms of artefacts' [SEED, p9, 1985]

SEED is an organisation which has developed from a perceived demand for an informal gathering of those directly involved in design teaching at tertiary level and is complementary to the major national bodies in the UK concerned with design. Members believe they constitute an informed body of opinion able to contribute significantly to the current debate about design and resolve it.

SEED's espoused aims are:

- to encourage the sharing of experience in engineering design education;

- to facilitate the viewing of design teaching departments;
- to provide a forum for the ventilation of matters of concern in design education;

- to represent the collective and informed view of members in the pursuit of a better understanding of design and an improvement in the quality of design education. [p4, SEED, 1988]

From a pure analyst point of view the definition given by Polak may be considered to be a complete one.

'Engineering design at its most restricted is finding the right thickness for a part when shape, function, loading and material are pre-decided' [Polak, preface, 1976]

Whatever the definition, the design engineer is a professional and the engineering industry has voiced its concern over the quality and quantity of these produced by the educational system [Wild, p23, 1983; Tolley, p28, 1986].

Being a profession, design engineering has many facets that are similar to other professions such as medicine, law and architecture. It would be of interest and relevance to compare the perceived characteristics of the engineering professional practitioner with those of other professions (see Chapter 3).

3. Assumptions underlying the research

In conducting this research a number of assumptions were necessary. The first is that practicing professional engineers would be most able and willing to provide the needed data and opinions. It is assumed that they knew, better than any other definable group, to what extent a designer's tasks are important now and in the near future.

The professional activities of this group are exclusively concerned with mechanical engineering. This is taken to imply knowledge. Indeed, the very high response rates reported (Chapter 4) confirms this confidence.
The second assumption is that the final year students in an honours degree sandwich programme (Chapter 7, p.171-174) would have had sufficient exposure to industry to be able to state in a concept-map format their perceived views of a professional engineer. This would be another source of data in the identification of the tasks performed and skills required for a professional engineer (Chapter 4, 5 & 6).

A third assumption was that colleagues involved in the education of engineers, in particular design engineers, would be a suitable target to elicit opinions on the ‘designer skills interaction model’ and propositions that were developed from theoretical research and data from the two groups above (Chapter 6).

Other general assumptions that were made include the following:

(a) Engineering design activity is the principal creative and co-ordinating force in any engineering enterprise. Therefore, skills identified for the professional engineer also apply to the design engineer and vice versa.

(b) Engineering design cannot be ‘purified’ and taught in a similar way as other engineering subjects.

(c) The formal educational process should exert the greatest possible influence on the professional development of the student.

(d) While the research does not negate the importance of reports by professional bodies and the industry’s call for greater technical competencies it does view the individual preparing for the profession as a partner in determining the curriculum.

Novak' [1984] has highlighted the fact that people are different and points to the tremendous variability in human beings. He argues convincingly that:

'we need to cherish, celebrate, and comprehend how beautifully various and inventive human beings are.
4. Organisation of the research

The first Chapter (this one) establishes the background and the need for this work. In Chapters 2 & 3 a review is given of literature on the various theories of learning that can be considered in the planning of a curriculum for mechanical engineering in general and engineering design in particular. Chapters 4 and 5 present the findings of the survey of professional practitioners in engineering and the data from students' concept maps on the skills for a professional engineer used in the development of the 'skills interaction model'.

Chapter 6 describes this model and includes a summary of literature research for theoretical underpinning of the professional skills items that are proposed for the skills interaction model. In the final section of Chapter 6 a refined version of the interlinked skills matrix model is proposed based on empirical data from Chapters 4 and 5 and an input from academics and professional engineers.

In Chapter 7 a sample curriculum in engineering design is developed to illustrate the application of the findings of the research. Finally, conclusions are drawn from the research work and some recommendations are proposed in Chapter 8.

References used are quoted at the end of the text and the Appendices follow these.
Chapter 2

Engineering Education - an overview

Man has learnt to conquer not only his immediate environment but has ventured out into space. He has progressed through the ages and history shows us that this progress has been dramatic over the recent past. Knowledge has made all this possible. He has learnt to educate himself and the future generations. Many different methods have evolved in communicating the existing knowledge from one to another. This process of education has always been a part of our lives.

Ancient schools and universities in the east practiced the guru-shishya (teacher-pupil) system of educating their young. The Greeks used the master-apprentice approach. Since then, for many centuries, all crafts, trades and professions have used the internship and apprenticeship methods for achieving competence.

As scientific knowledge and information became widespread and readily available the manpower demands were for well educated and trained professionals. Today with the rapid growth of science and technology the demand is for individuals with the ability to keep pace with this trend.

Engineering curricula kept pace, first emphasizing the mechanic and practical arts necessary for land development, then the skills necessary for creating and operating a mechanised and technology driven industry. Later it included mathematics and the sciences that were eventually necessary for the development of electronics, automation and space exploration [Grayson, p11, 1977].

In the first half of this century, the education of an engineer was strongly oriented towards the technology of engineering. The academic content of most engineering courses contained some classical subject areas
like mathematics, mechanics, thermodynamics and fluid mechanics together
with a strong emphasis on manufacture, operation, testing and maintenance
of equipment and facilities.

There was a need for all engineering graduates to acquire some
'machine shop' skills. It was essential to spend time in bench fitting,
basic machining, pattern making, foundry practice, welding etc. A large
percentage of the engineering student's contact time was spent in
laboratories. Until recently up to thirty contact hours per week were
involved in this type of experiential activity [Harrisburger, p2, 1976].

In the post-Sputnik second half of this century, there was a strong
shift to research and development oriented courses. New scientific
discoveries made the engineering of many systems possible that were
previously not. The ever-increasing power and capabilities of the computer
has made the analysis of problems and solutions almost instantaneous.
Information and data can be accessed from central sources. Curriculum
development has strived to keep pace with these changes.

With these rapid changes the current debate in curriculum developmment
is focused on the breadth, depth and flexibility among engineering
graduates. There is a need to continually examine the adequacy of fit
between the courses, the needs of the employer and the student. It is also
clear that an engineering education is increasingly accepted as a sound
general education for entry into different career paths [Boley, NAE 1980].
Many graduates in engineering, particularly in the USA, have gone on to
pursuing further education and employment in fields such as medicine, law
and business [Grayson, p56, 1977].

There is, however, no optimism in respect of the preparation of future
generation of engineers. One view expressed by Sir Peter Carey of the UK Government is that

'it would be surprising if any group of people could lay down such a complex blueprint and get every detail right at once'. Carey goes on to warn us saying that 'In this period of self analysis engineers must beware of the dangers of excessive introspection. Professional excellence is not, for an engineer, an end in itself, it is merely the means to an end'. [Carey, 1979, p. 446]

The reference in this context was to a report to be released in 1980 by Sir Montague Finniston on the state of the engineering profession in the United Kingdom.

Unlike the Continental pattern of engineering education the British system has three distinct events that played a major role in shaping its process - the introduction of engineering sciences at the universities, the development of the local technical colleges from the mechanics institutes and the formation of the many professional bodies some of which have Royal Charter status. The interactions of these entities has been studied [McCormick, 1985] and compared with the practices in the Continent.

The overriding difference in the two systems is the relatively minor role that the state played in the education of engineers in the UK and the close linkage of the engineer and his education with the national ambitions in the Continent.

Perhaps the current state of the manufacturing sectors in West Germany and France combined with the status of engineers in those countries add credence to the wisdom of such national integration. With this level of involvement of all sectors of the community it follows that any developments in courses and curriculum has the input, guidance and support of the highest authorities in the land. It also ensures that those involved
in it get their deserved recognition. This has all the ingredients for success in the multifaceted discipline of curriculum development in engineering education.

In the USA, the range of engineering courses is extensive and diverse. A National Commission on Accreditation (NCA) supervises the general conduct of accreditation. The Commission recognises the Engineers' Council for Professional Development (ECPD) as the sole agent responsible for accrediting all degree courses in engineering. Around 1,600 courses are currently accredited by ECPD.

The ECPD curriculum content guidelines, although explicit, provide ample latitude for curriculum innovation and development. Within these guidelines the majority of institutions have developed a fairly standardised curriculum format for the degree courses. In effect the engineering programme is an upper-level two year course with the first two years devoted entirely to in depth study of mathematics, physical sciences, humanities and communications.

In the USA engineering is regarded as one of the most difficult programmes in the university, comparable in rigor and selectivity to medical schools. It is interesting to note that the freshman at an engineering course in the USA is 'socially introverted, mechanically oriented, and weak in communicative skills' [Grayson, 1977]. Such information on the raw material is useful in the development of the detailed syllabus in an area of the engineering curriculum.

Japan has also been cited as an example to emulate. There a national education system was introduced in the nineteenth century (in 1872) after a team of high ranking Japanese Government officials studied at first hand the systems of education used then in the US and Europe. Foreign technical
experts were imported, often paid more than the Prime Minister of Japan. It has been suggested that the UK 'should contrast this positive approach with (our) own rather dilatory Finniston and post-Finniston approach to solving problems' [Lorriman, 1986].

Japanese engineers have a very broad education. Much of the technology specific training is left to the industries concerned. This enables the universities to concentrate on the basic engineering sciences and provide a generally rather relaxed degree courses. Japan also produces a higher proportion of engineering graduates out of the same proportion of university entrants as many European nations [Lorriman, 1986; Hutton, 1986]. Hutton states that from the Japanese employer's point of view the fact that graduates have a degree is no proof of their ability as engineers. The post-graduate in-post training is effective even if it is rather unsophisticated.

Finniston [1980] found the Japanese approach to engineering to be totally market oriented. Even basic research work is undertaken to achieve explicit market goals. Engineering, in fact, is perceived by engineers and management alike as a linchpin of a commercial enterprise.

This philosophy extends to product development where the start is the identification of a particular market need or gap. This indirectly pressurises engineers to seek innovative designs and new inventions. In fact, in one electronic company it is compulsory for all research engineers to register at least four patents annually each.

Hutton [1986] has pointed out that there may be more creativity, inventions and original thinking in Europe but in Japan there is more innovation. Unfortunately, there is very little research work or
publications relating to this superior innovativeness of the Japanese people.

Undoubtedly the education of the engineer in Japan has a real and significant influence on the development of the skills necessary for this superiority. If such skills were to be identified and a schema for their development established then the curriculum for the engineering courses could be studied and copied elsewhere - resulting in improved innovative skills, perhaps.

In the UK a mechanical engineer is perceived to 'occupy a key central role in the (UK) economy, often as the focal point for a range of engineering functions and expertise within a multi-disciplinary system' [IMechE, 1986]. There are guidelines given for the development of courses and curricula. These anticipate the variations possible in the teaching methods, balance and time-tabling methods. As a general rule the theme is to give a progressive shift of emphasis from engineering sciences and principles in the early stages towards a more integrated study in the later stages.

Irrespective of geographic location of institutions some of the common issues that face the educator in engineering are:

- Secondary schools related problems of lack of emphasis on science and mathematic and career counsellors not sufficiently knowledgeable about engineering careers [Tolley, 1986]

- Quality of education in terms of readiness for employment

- Engineering vs engineering technology (BSE vs BSET) [Boley, 1980]

- Communication skills

- Curriculum content and Non-technical subjects in curriculum
- Computers in engineering

- Prestige vs Practicality [McCormick, 1985]

One major issue that is brought up in one form or another in almost all research papers on engineering education is the necessity for all engineers to be involved in engineering design at the undergraduate level [Ashford, 1968; Kimber, 1972; Caulkin, 1979; Finniston, 1980; SEED, 1985; Smith, 1986].

The importance of design has been recognised and the ‘issue has reached the highest echelons of Government’ [Sheldon, 1984] in UK where the Prime Minister chaired a seminar on the importance of design held at 10 Downing Street, London. A similar picture emerges in most industrialised nations where the major effort in engineering education is in the preparation of graduates for a career in engineering rather than imparting knowledge in ‘core’ subject areas.

Thus it is clear that we must seek new paradigms and new approaches that will enable educators to ‘treat’ design as a vehicle for developing skills needed in the engineering profession today and in the foreseeable future.

**Engineering Design Education - a review**

During the period of the industrial revolution in Europe and through the machine age the art and science of engineering design was learned - not taught. Engineers such as Stephenson and Brunel achieved their successes by being involved from the conceptual to the final commissioning stage of their ideas. Every step was planned and executed by these engineers. They were also physically close to their products. They developed an all-round ability in bringing to practical reality their concepts of engineered
systems.

Today, engineers are considerably removed from the actual products. With the help of computers they are able to analyze mathematical models of designs without the help of prototypes or testing. This combination of an education that favors analysis and not synthesis and little significant hands-on experience has shaped the way today's engineers attempt to solve problems [Mistree & Muster 1984].

In a paper presented at a design conference in the UK, Wilde [1983] says:

'So much has been written and debated about the education and training of design engineers over the past 20 years that one could be forgiven for thinking that their value to industry is well understood and their supply amply provided. Despite all the good intentions and recommendations the response has been disappointing. There are basic reasons in our education system that are responsible for this sad state of affairs.' [p21]

The education of design engineers and their supply are in question here. Wilde continues to describe the scenario of the future when the number of existing experienced designers is diminished and industry is not able to replace these posts. He further submits that:

'it is the general lack of appreciation of the importance of the engineering design function both by industry and the education system in schools and universities' [p21]

The Fielden Report [1963] had brought to the attention of educators twenty years earlier the points that Wilde considers fundamental to the education of engineers. The major issues addressed by Fielden and supported by Wilde are

1. The switch from the apprenticeship/part-time Technical College training to school/full-time university training ..... produced graduate ..... ignorant of design function...
2. Even if education guaranteed higher academic standards, .... would not compensate for the loss of .... early introduction to design thinking. ....

3. a surfeit of academics and a dearth of skilled designers is a sure passport to failure. .... ideas have to go through the design office to achieve anything in practice.

4. bias towards academic attainment, mutually beneficial to students and teacher, is automatically self-perpetuating. The less obvious but no less valuable creative talents are passed over. .... a most serious fault...

5...there needs to be a revolution in thinking in the assessment of ability for an engineering career and particularly for engineering design.

6. The encouragement .... of CDT in schools and uprating of engineering design in colleges, polytechnics and universities ....

7. The desirability of a link between industry, ..and universities.... perhaps the only way to influence thinking in the vast education machine....

8. communications and collaboration between the existing craft departments and academic teaching staff.....

9...placing of engineering graduates,directly into a large design office has been a mistake. ...

10. Design Induction Scheme for graduates ... master/pupil relationship separated from the critical gaze of the mass. ...

11. ..transfer to more committees design offices ... active design schemes. ...

12. ..practice and expression .. encouraged and developed in the early years.

A further argument put forward by Whittle is that the 'gulf between universities and society is reflected in the chasm which exists between university educated designers and the technical college educated manufacturers.' [Whittley, 1984].
Whittley lays the reason for this situation with the validating body, CNAA, for creating the policy of educational apartheid. In the words of this educator,

'CNAA has inflicted more damage to the British industry than the Luftwaffe did during the war'.
[Whittley, 1984, p53]

The gap between college and industry, according to Whittley, is caused by the 'separatist higher education policy' [p54] and the damage done by this educational apartheid cannot be rectified overnight. In an earlier article [Whittley, 1982] he says:

'Back in the good old days we knew precisely what we were, everyone also thought they did and most things were going well.' [p65]

Mistree & Muster [ASEE,1984] argue that while our efficiency with the skill with which a design method is implemented and applied has shown greater improvement our effectiveness has not. In their view many modern engineering catastrophes are attributed to the failure of modern engineers to appreciate the importance of non-linear spatial thinking. The role of synthesis relative to analysis in the education of design engineers has been raised here.

Design competence required today, according to Christopher Jones [1984] is:

'not that of deciding the shape of a product or system but the shape of a new context or process in which everyone, not just designers or experts, is enabled to see what is needed of him or her if the form of industrial life is to get better, for everyone, and not worse'. [p79]

Competence, however, is a complex concept, involving technical knowledge, relevant experience, transferable and specific skills and attitudes. In the engineering design context it is the possession and development of the the above characteristics required for the successful
performance as a professional design engineer - the ability to deal with novel and well established tasks [FEU, 1985].

In mechanical engineering there is a tremendous breadth of design activities and design is only one of many elements that make up the profession of engineering. Numerous design activity models show a wide spectrum of characteristics required in the designer.

Gill [1983] compared the various design fields and produced a generally acceptable illustration (Figure 1) showing the spectrum of design activity. Such a demarcation places engineering design in the context in which it should be viewed. The differences across the spectrum cause confusion both in the layman and the expert. There is, in particular, a strong argument for the engineering design and industrial design areas to be merged to 'restore the wholeness of design' [Ashford, 1968].

![Figure 1: Spectrum of design activity](image)

Heywood and his colleagues [1966, 1975, 1981] have done some early work in gathering information about the work done by engineers. Their studies showed that the range of tasks carried out was much wider than that assumed in existing degree courses.

Cross [1982] proposed a model, a 'third culture', following CP Snow's two identified ones of art and science. The model for the third culture,
design, has three aspects:

- the man-made world,
- modeling, pattern-forming, synthesis and
- practicality, ingenuity, empathy & appropriateness.

The education and training in any of the three cultures involves the following three fundamentals:

- the transmission of knowledge about a phenomenon of study,
- a training in the appropriate methods of inquiry, and
- the initiation into the belief systems and values of the culture.

Sheldon [1984] suggests that the above model, while not sufficiently comprehensive, sheds light on the intellectual skills, sensibilities and values that designers should exhibit and hence provide a guide for education and training priorities. Kalanidhi [1984] stresses the need for character development in engineering undergraduates with a 'four domain' model, in particular for developing nations. It is difficult to distinguish this proposal from the engineering courses that have traditionally included classroom, laboratory and industrial training domains. Perhaps professional ethics can be substituted here in preference to character development - an area related to all stages of education and life.

It is clear, however, that design education has been more analytical and definitive rather than synoptic and formative [Ashford, 1968; Muster, 1984; Sheldon, 1984; Carter, 1984]. Ashford concludes that human aspects of engineering are generally ignored [p1961]. He also points out that the establishments devoted to engineering education are partly at fault. They have not seen the 'writing on the wall' and have not done anything to improve the situation. Carter suggests that today's graduates are 'ill-
prepared for the complexity and compromises of engineering problem solving'. He says:

'Thus it is desirable that the learning experiences which form the curriculum should be studied from an experiential point of view to assess their contribution to personal development. It is only when this step is taken that an engineering course can be said to have moved from being a job-specific training to being an education for a professional career.'

[Carter, p682, 1984]

Writing about engineering designers, Muster claims that the educational system - from grammar schools to university - have virtually ignored the problem of training creators, inventors, synthesists, and generalists [Muster, ASEE, p39-42, 1984].

Muster, in another paper proposes courses based on design harmonisation and adaptive action learning to prepare students for the 'Systems Age'. Harmony follows, according to this author, when the flow of the problem solving process is characterised by smoothness, not abruptness [Muster in CME, p3, 1984].

While this collective view may prompt research into the various aspects of engineering design curriculum the fundamental debate on design education continues to be whether design should be equated with problem solving. Industry sponsored and real life design projects are suggested by Brichta for the successful teaching of design. According to Brichta [1984] 'only when an enlightened and meaningful combination of industrially relevant training and professional experience is achieved could it bring design and creative problem solving to a focus in the mechanical engineering curriculum.' [p46]

SEED [1985] was divided on the question of what the core material and its inter-relations should be in design education. The Working Party agreed

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finally that the purpose of design was to meet human needs in terms of artifacts.

The models they agreed on are shown in Figure 2 and Figure 3. SEED viewed design as central to engineering; trans-disciplinary; highly complex, iterative and interactive. Skills required in the designer were identified as communication, creative, analytical and the ability to integrate, judge and manage.

Sheldon's [1984] model for design as a problem processing system using information as a processing agent treats design simply as a problem and suggests that designs differ only in that the type and number of problems vary with each design. This approach is protean enabling the intellectual skills associated with creativity to be activated at all stages of the design. Figure 4 shows this approach as given by Sheldon & Gill [1984].

Thus, there appears to be many common and some contradictory views expressed by various authors and authorities on the subject of engineering design education. However, for today's educators and researchers these views are still not satisfactory. The situation lacks the clear perspective to enable a confident statement to be made on the general education of engineering designers, let alone the curriculum details. The perennial questions are still not answered - can design be taught? And if so, how? What should the curriculum for design include? Why?

There are many variables in the design ambience which make precise statements about design education difficult to justify. Whatever the design problem, one ever present variable is the designer himself. It is, therefore, obvious that the prerequisite of a successful design is the need for a good designer or design team. A stimulating environment is another factor without which even a well trained designer could become less
Figure 2: Design Activity Model [Prof Pugh in SEED, 1985]
Figure 3: Elements of Specification [Prof Pugh in SEED, 1985]
Figure 4: Design as a problem processing system using information as a processing agent [Sheldon, 1984]
creative. The design activity is also dependent for its success on the quality and quantity of available facilities such as computers, data and information together with sound management [Constable, 1986].

In an educational context these factors are compounded by the academic environment in which resources are geared to studying rather than 'doing' at one's own pace. Engineering students are more in libraries than in workshops and design studios. Some industrial design courses have partly overcome this imbalance by devising curriculum which are project based.

But mechanical engineering courses have yet to come to terms with this situation - in many instances the imbalance is not even acknowledged or realised. New paradigms in education are necessary to bring engineers into closer harmony with real-world problem solving and to acquire intuitive skills associated with viewing problems holistically and, where possible, hands on experience that will enhance these skills [Mistree, 1984].

Within the framework of the Engineering Council policy (statement on the routes to registration as an engineer), its documents suggest that programmes can be devised so that students may achieve the levels of competence required and develop the intuitive skills to handle problems in the systems age [EC, 1984]. However, no guidelines on the syllabus preparations of such courses are provided.

Black & Bradford [undated] of the University of Bath consider that the problems in planning a design curriculum (see also Chapter 3, p36/37)

'lie in the nature of the activity itself. ... It cannot be purified and taught as a classroom subject'.

These two educators consider Bloom's taxonomy [1956] a good guide in their efforts at classifying objectives for a design course operating at
many different levels of complexity. The background subjects and laboratory work cater to the 'knowledge', 'comprehension' and 'application' objectives while the design syllabus is devised to cater to the 'analysis', 'synthesis' and 'evaluation' levels of activity. Course syllabus was written in objective format.

It is interesting to note that the Post-Graduate Design Education Panel of the Science Research Council in the UK considered the Bath University course aims and objectives to be relevant to all design courses. These were issued in 1973 as a 'framework' for all University courses in engineering design. Unfortunately, SEED [1985] does not include Bath University faculty in its deliberations. So, there is apparently differences of opinions on engineering design education at the national level.

At an international level, given the various stages of industrial development that exist in different nations, and indeed the differences in regions within a nation, it would seem impossible to evolve a general ethos for design education. The spread and absorption of technical knowledge within the population of any nation is dependent to a large extent on its prosperity and socio-economic conditions.

In some nations, like India, the original purpose of an engineering education was to produce an efficient class of sub-ordinate officers for employment in the Department of Public Works, the Survey, the Railways and to some extent for the Defense sector [Grayson, p26, 1977].

This restricted the technical education to civil engineering until the beginning of the century. The products of such a system were also called upon to establish and man the future tertiary institutions. The areas of emphasis in the education of engineers were perpetuated until consumer
demands increased sharply in the second half of this century. This in turn necessitated the production of more engineers and quantity was the order of the day. Now the pressure is on to improve quality of products and this has forced faculty to look into the design curriculum seriously.

Academics in these nations are also faced with the same problem of identifying what should be included in an engineering design curriculum. The technology that interests these developing nations is one that has grown within the womb of European civilization over the past 150 years, particularly since the industrial revolution. But the transfer of such an 'enclave without forward and backward linkages' [Goonatilake, p120, 1984]
does not, de facto, bring with it any transferable design culture or ethos.

In other words, while the technology can be easily transferred and absorbed the history and philosophy of western science and technology may not permeate to the undergraduate. This is major hurdle for the academic in formulating courses and curricula for engineering design.

Adapting Simon's [p 228, 1981] philosophy on the transmission of knowledge in the educational process, we could say that in engineering and technology, the progress from elementary to advanced levels is to a considerable extent a progress through the conceptual history of engineering and technology itself. If engineering design is considered an advanced level of activity, then it could be argued that to be a good designer it is essential to have a sound appreciation of the history of engineering and technology.

It follows, then, that a curriculum for engineering design should include a study of the history of engineering and technology. For a developing nation this is perhaps even more important to include in the
education of technologists and in particular the education of design engineers.

It is obvious from the plethora of publications that design education in the engineering field is both complex and diverse. No suitable guidelines exist for the development of curricula for engineering design. The problem appears to be a worldwide one and there are many efforts at creating a model for this, most being centered on individual institutions. Some, like SEED, are making a concerted effort along a 'common interest' philosophy rather than a research approach.

With such a dearth of research in tertiary engineering education, particularly for design, it would be foolish not to consider the vast amount of research that has been carried out worldwide in education at the school level.

Much of this work is psychological in nature and generally deals with North American infants and adolescents. The learning theories developed from this base has been of interest and benefit to educators elsewhere. Educational psychologists have categorised human behaviour and established various levels of performance that can be achieved by learning throughout a person's life.

While skills and characteristics needed for an engineering designer may be unique, the learning process is, perhaps, common to the secondary and post-secondary stages of education. A study of the theories of learning is, then, an essential step in the development of a Design curriculum. This must be viewed from the point of view of the education of the professional engineer.
Professions profess. Individuals in a profession assert that they know better than others the nature of their specialisation and discipline. Every professional evolves an idiosyncratic style moulded by his education, training, personality and influenced by the past and present environment he inhabits.

In the engineering design field, the majority of practitioners fulfill the key characteristics of it's professional occupation identified in the literature, i.e.

(a) they are required to be expert in a particular area of activity, for which an advanced and extended formation is necessary, and practice which requires a high level of theoretical foundation;

(b) they have custody of a clearly definable and valuable body of knowledge and understanding;

(c) they accept responsibility and accountability for decisions they make against recognised values and standards of conduct.

[Finniston, p125, 1980]

Unlike most other professions majority of engineers are employees of companies and other organisations and the range of activities carried out by engineers is greater than most other professions. Invariably their work does not bring them in direct contact with their ultimate 'clients'. Hence, while their products or systems may be subject to detailed regulations, engineers themselves have not in general been subject to stringent legal controls which apply to other professional services provided for the lay public.

The Council of Engineering Institutions (now the Engineering Council, EC) formulated its own Code, designed to provide a general model for the
codes and rules of conduct applied by member Institutions. It stated:

"The Chartered Engineer shall at all times so order his conduct as to uphold the dignity and reputation of his profession; and to safeguard the interest of the public in matters of safety and health and otherwise. He shall exercise his professional skill and judgment to the best of his ability and discharge his professional responsibilities with integrity."
[Quoted in Finniston, p139, 1980]

Finniston went on to recommend that registered engineers should:

(a) not undertake work for which they could not validly claim competence;

(b) maintain and develop their competence through participation in continuing formation programmes;

(c) maintain their knowledge of, and to observe wherever appropriate, technical standards, codes of technical practice, health and safety regulations, and other such requirements; and

(d) participate in and to encourage the formation and professional development of other engineers.
[Finniston, p139, 1980]

To be an effective professional engineer an individual must first acquire the knowledge and skills defined by the profession and then be able to apply this to the solution of specific problems or issues. This application involves processes that are complex and are performed by an awareness and appreciation of major engineering principles rather than by routine analytical skills. Insight and judgement are essential skills needed for this. This could be defined as professional technical competence. This establishes the base for all engineering activities and embodies both cognitive and behavioural aspects. An engineer, however, cannot function effectively on technical competence alone [Bately, p44, 1987]. As a professional, the engineer must also achieve a sense of identity with self and the profession. As in other professions, the social
status and professional identity will provide the interpersonal basis for practice.

Engineers differ, however, from other professions in some important ways. According to Batley [p44, 1987], the perceived differences between engineers and other professions, in terms of interpersonal traits, are:

1. Engineers have strong quantitative skills, but compare unfavourably in verbal skills.

2. Report writing and communication skills are often undervalued; engineers concentrate on quantitative techniques.

3. ... happier with machines, drawings or calculations rather than people.

4. ... believe products and achievements should speak for themselves.

5. ... fewer interpersonal skills.

6. ... dislike internal politics, their career planning and development is neglected.

7. ... are more comfortable with an enduring environment; this creates resistance to change.

8. Many engineers find difficulty in delegating.

Much of Batley's observations relate to acquired values and norms of how engineers define themselves and how others view them. It is, however, clear that technical competence and identity are interlinked and influence the effectiveness of the engineer. Therefore, they need to be addressed at the early stages of education of the engineer - with the support of relevant theories of learning for each behavioural aspect to develop necessary curricula details.

Educational Psychology in Engineering Education

Educational psychologists have branched the spectrum of human behaviour traditionally into three main streams - the cognitive, affective
and psychomotor domains [Bloom et al, 1956; Krathwohl et al, 1964; Guilford, 1958]. From the educator's point of view Gagne [1977] has suggested five major categories of human performance that may be established by learning: intellectual skill, verbal information, cognitive strategies, motor skills, and attitudes. The details of these categories relate very closely with the educational segment of an engineer's formation. Hill [1980] says of Gagne's views:

'have implications beyond either schooling or applied training; they indicate the way in which our whole structure of knowledge and skills is built up throughout life.' [p120]

The five categories listed by Gagne can be applied generally to education at all levels and in all disciplines. However, in the area of engineering design very high levels of intellectual and cognitive skills are demanded. Therefore, the intellectual skills and cognitive domain branches of human behaviour may be the important ones to address in the development of engineering design curricula. Within this cognitive domain there are six different levels of increasing sophistication. Figure 5 shows Bloom's taxonomy of objectives in the cognitive domain [Bloom, 1956] and Figure 6 illustrates Gagne's classifications.

It is evident from the figures that authors of the taxonomies have listed a bewildering sequence of steps and branches of learning. These can, however, be summarised into the five or six levels (as shown in Figure 5) for each of the four basic taxonomies. The objective here is essentially to provide a simplistic "layman's" interpretation rather than a comprehensive comparative study. It also acts as a guide in the development of effective learning activity (Section 2.1, Chapter 7) in a curriculum model.

In each of the domains (Figure 5) the first three levels in the
Taxonomies can be interpreted as infant-level activities of learning. The next three levels - IV, V and VI - may be interpreted as adult learning activities. These involve judgemental activities and need complex mental skills to apply knowledge and draw on previous experience in handling and solving new situations and problems. In other words, levels I, II and III involve training and levels IV, V and VI involve education. It is the higher order levels that develop the decision-making and problem-solving attributes that are desirable in and are fostered by design engineering experience [Harisburger, p5, 1976].

Black & Bedford [undated] have adopted Bloom's [1956] taxonomy of educational objectives in arriving at their syllabus content for design education at Bath University. They have identified the higher three levels of Bloom's objectives to be the required stages for the design activity. They were, however, unable to start the construction of the course without establishing a 'model' of a designer in industry which 'the student designer should aspire to become'. The definition of a designer chosen by the Bath team is detailed and comprehensive:

'Engineering design is the use of scientific principles, knowledge, imagination and judgment in the definition of a structure, machine device or system to perform particular functions with the maximum of efficiency and effectiveness'.

The above definition is also used by the Aeronautical and Mechanical Committee of the Science Research Council in its guidelines. Many other definitions exist and each in its own way is a statement regarding the diversity of activities that encompass engineering design. Consequently the educational objectives for an engineering design education is both complex and variable. One bibliography on the taxonomy of educational objectives for technologists has a 167 page listing [Heywood, 1975].
## Comparison of Taxonomies of Learning

<table>
<thead>
<tr>
<th>LEVEL</th>
<th>COGNITIVE</th>
<th>AFFECTIVE</th>
<th>PSYCHOMOTOR</th>
<th>EXPERIENTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Knowledge</td>
<td>Receiving</td>
<td>Perception</td>
<td>Exposure</td>
</tr>
<tr>
<td>II</td>
<td>Comprehension</td>
<td>Responding (Willingness)</td>
<td>Set (Willingness)</td>
<td>Participation (Application)</td>
</tr>
<tr>
<td>III</td>
<td>Application</td>
<td>Valuing (Acceptance)</td>
<td>Guided Response (Execution)</td>
<td>Identification (Involvement)</td>
</tr>
<tr>
<td>IV</td>
<td>Analysis</td>
<td>Organisation (Importance)</td>
<td>Mechanical Response (Habitual)</td>
<td>Internalisation (Adoption)</td>
</tr>
<tr>
<td>V</td>
<td>Synthesis</td>
<td>Characterisation (Adoption)</td>
<td>Overt Response (Perfection)</td>
<td>Dissemination (Commitment)</td>
</tr>
<tr>
<td>VI</td>
<td>Evaluation</td>
<td></td>
<td></td>
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</tbody>
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Figure 5: Comparison of Taxonomies of Learning (Adapted from Harrisburger, 1976)
Gagne's Learning Hierarchy

I  Response          Imitate
II  Association      Name
III Discrimination   Select
IV  Behaviour Chains Order
V   Classification   Identify
VI  Principles       Apply a Rule
VII Problem Solving  Apply Principles


Figure 6: Gagne's Learning Hierarchy
Heywood (1981) has indicated that behavioural sciences can contribute to the formulation of policies in engineering education. He has pointed out that the issue of the interaction between basic science of engineering (knowledge) and skills in the job needs more substantive investigation. This calls for a role and needs analysis in the local industries to establish the skills required for the engineering design practitioner.

Another novel method has been suggested by Waks (1984) where the learning activity is analysed through an engineering approach. Here the main components are: input (raw data), output (processed data) and conditions of learning (bias). The components are interconnected in a closed loop feedback pattern, including 'impedance matching' to optimise the learning process. Waks admits, however, that the feasibility of a pure logical-mathematical approach is limited as the ingredients (variables) cannot be treated in complete isolation.

Leo West (1984) uses a vine metaphor in describing the integration of two sources of knowledge (the two vines) acquired by an individual. The first is the knowledge that a person acquires from interaction with his environment and the other originating from formal instruction, discipline knowledge, school knowledge. Both are learning processes. In a rather idealised topology West calls the situations in his metaphor the conflict, congruent, symbolic knowledge and the uninstructed.

Concept mapping (detailed in Chapter 5) is a technique suggested by West in helping the learner to integrate and differentiate the symbolic knowledge. The uninstructed situation demands intuitive learning and research cited by Hewson (1984) demonstrates the powerful influence of cultural metaphors in shaping concept acquisitions. An analysis of
engineering design education in the local scenario may identify problems in adopting curricula developed elsewhere.

If creativeness or innovativeness is an implicit and important aspect of engineering design [Ashford, 1968; Caulkin, 1979; Sheldon, 1984; SEED, 1985; Smith, 1986; Pudlowski, 1987] then it may be relevant to consider personality traits in the study. The psychologist's profile has some interesting special characteristics relative to the generic profile found for the scientific profession. According to Cattell:

'as far as the dynamics can be inferred from personality factors, however, ego strength and security from neurotic anxiety, the freedom from vulgar environmental distractions conferred by the high degree of invia (and steady home attachments), the contribution of independence in thinking brought by self-sufficiency and dominance, a mind directed away from superficiality and impulsiveness (through tying the safety valve down by desurgery - inhibition), the overprotection of high I, and the internal productiveness of autia, are the main roots of creativity in most fields. and except for high general intelligence .. personality certainly contributes much more than special abilities to creativity and inventiveness'.[Cattell, p243, 1970]

Cattell's study refers to many professions but in engineering and technology the closest careers studied are time-study engineers and air industry personnel - airline pilots and aircraft engineering apprentices [Cattell, p189, 1970]. Such studies for design engineers in any industry is not available in any published form.

Nevertheless, there are some pointers in the above statement for researchers in curriculum development in engineering education at tertiary level. Cattell does point out that very little has been researched on personality and the educational process, particularly at the college level.

While it is not intended to guide this research work in a purely psychological framework, it is now accepted that psychology is to education
as mathematics, physics and chemistry are to engineering or biology and chemistry are to medicine. It is clear that the interdisciplinary approach of cognitive science using insights from linguistics, philosophy, computing science, engineering and psychology could be the route to the understanding of human mentality [Sanford, 1987].

This research will, however, dwell less on the arcane subtleties of educational psychology and concentrate more on developing a paradigm of learning in terms of requirements for a professional engineering design education. It is necessary, then, to have an overview of some of the various learning theories in educational psychology.

**Learning**

Two opposing positions in epistemology are empiricism and rationalism. Empiricists view that experience is the only source of knowledge. The rationalists have the general philosophical position that the prime source of knowledge is reason. Both appear to have problems characterising learning. Hence learning is one of the major areas of investigation in psychology and is the centre of a great deal of controversy. The study of learning may be aptly called experimental epistemology [Bower, 1981].

In some aspects, research on learning has become more applied, with the development of behavioural technologies as one consequence. Cognitive information processing concepts is another area of today's research. There are increasing efforts to build bridges between theories in the two divisions. The simplest theories of learning are those based on Pavlovian conditioning, but modern approaches emphasize cognition and invoke cybernetics and mathematical models of considerable sophistication. New areas such as Cognitive Ergonomics [Sanford, 1987, p118] focus on our
learning skills using computers and other high-tech devices.

It is not the intention, and indeed not necessary, in this research to cover all theories of learning and education. Selected theories considered applicable to the education of engineering designers are reviewed to the extent that the major stance in them are identified.

It is essential at this stage to define what we mean by 'learning'. According to the American Heritage dictionary, to 'learn' means "to gain knowledge through experience"; but one of the meanings of 'experience' is "to perceive directly with the senses," a meaning that appears initially in the definition of 'know'. But 'knowledge' is defined as learning through experience and learning is defined as acquired knowledge [Bower, 1981]. So much for the American Heritage dictionary.

Novak & Gowin [1984] say learning is the result of change in the meaning of experience. Gagne [1977] argues that learning takes place when stimulus situation together with contents of memory affect the learner to change his performance. Another approach is to view the learner as an active sense maker. This implies a distinction between private understanding and public knowledge. Learning is, then, making one's own sense of public knowledge [West, 1986].

Gagne's [1977] listed categories of learned capabilities are very relevant in the education of the design engineer (Figure 6, p39). Clearly there is a hierarchy inherent in the intellectual skills developed through learning. At the apex there is the higher-order rules requiring rules as prerequisites. These rules require the manipulation of concepts which, in turn, must be discriminated one from another and from extraneous entities. This hierarchy implies learning is cumulative and it is this ability to accumulate intellectual skills that enables the solving of a variety of
novel problems [Gagne, p152, 1977]. This is, then, an important aspect of an engineering designer's education.

According to Harrisburger (1976) all engineering activities are 'doing' activities and are best learned by experiencing. The basic strategy as proposed by Harrisburger et al is to interpret the three higher levels in Bloom's taxonomy (Figure 5, p38) as adult learning activities. The first three, he claims, involve training and the last three involve education.

In the upper three there is some overlap and correlation between the cognitive levels of analysis, synthesis and evaluation and corresponding levels in the affective and psychomotor domains. The point is then made that:

'It is these three upper levels that develop the decision-making and problem-solving attributes that are so highly valued in graduates of engineering and other professional schools. These are the attributes that are developed by engineering design experience'. [ibid, p5, 1976] (My underlines, not original)

Experiential learning here is used in the context of the fundamental axiom of 'practice makes perfect' and as understood by North American educationalists [Harrisburger, 1976; Steinaker, 1975]. In particular, the term implies learning by doing and is considered an important component of the educational process in engineering courses.

Many taxonomies (classifications of educational objectives) document the learning sequence of students in their learning process. The sequence traces the levels of sophistication achieved by the students from the beginning characteristics to the limit of behavioural change. Figure 5 shows a cryptic summary of these steps with the experiential component and it's various levels.
Harrisburger studied six experiential learning models related to
ing engineering education in the US:

1. The Worcester Polytechnic Institute PLAN programme
2. University of Massachusetts ESIC programme
3. Harvey Mudd College Clinic programme
4. University of Cincinnati Professional Practice programme
5. West Virginia University PRIDE programme and
6. Kansas State University Mechanical Engineering Design Laboratory

Each is uniquely different in concept and implementation. But they
were all experiential learning situation models. While the workings of the
above schemes are well documented there is a lack of information on the
learning processes involved in each situation. However, the experiential
learning objectives inventory provided (Figure 7, p. 47) is a good guide
for developing curriculum content in the education of engineers.

Gagne [1977] has identified two primary sources of human capability in
solving problems: the intellectual skills (concepts and rules) and
cognitive strategies (internally organised skills). The most generic power
and problem-solving potential for problems in a particular discipline lies
in the greatest generality and inclusiveness that the cognitive strategy
can command [Ausubel, p524, 1969].

Engineering design also demands the above skills. Sheldon [1984]
suggests that the intellectual skills associated with 'conceptual' stage
need to be activated - hopefully creatively - at all levels of the design
process. He says, however, that

'despite an enormous though recent understanding of
design it is clear that some confusion still
exists. ... Design is simply a special kind of problem-solving'.

Is not the entire field of engineering one of solving problems? If so, should we not teach all subjects in engineering within the framework of solving problems? If this were considered the most suitable approach in engineering education then Moulton's view [1976] that engineering should be taught in the context of design and that students should be encouraged to deal with the 'problems and disciplines of conceptual thinking' must be applied to any curriculum development in engineering.

Moulton's view is echoed, although indirectly, by recent reviews of engineering education in the UK. If we are to get away from the 'text-book solution' mentality [Finniston, p83, 1980] of engineering graduates then the general learning ability must be fostered in preference to the 'examination passing ability' [Furneaux, 1962] which persists - certainly in the developing countries. The implication here is, surely, for the development of 'abilities'. Any curriculum must reflect, over and above the theoretical knowledge content of the course, the way in which we perceive learning of abilities will be effected.

Such an input into a curriculum requires in the authors of curricula an understanding of the way in which student study and learn in a particular environment. Paul Ramsden [Marton, 1984, Chapter 9 ,p151] highlights the lack of research in the way students study and learn. He states that, in the UK, the ethos of higher education emphasizes individuality and autonomy. Success is seen as a reward for a student's own efforts and ability. He argues that lecturers, however, have 'far-reaching influences on learning'. The quality of teaching is 'functionally related' to the student's attitude towards studying and approaches to learning.
Skills and Attributes for a Professional Engineer

[as developed by Prof Harrisburger et al, 1976]

Problem Solving Skills
Interpersonal Awareness
Creative Expression
Communication Skills
Technical Skills
Self Confidence Building
Computation Skills
Engineering Fundamentals
Organisational Skills
Leadership Skills
Planning Skills
Professional Ethics
Engineering Judgement

[Harrisburger, 1976, p7 : "Any combination or all of these skills, can be program objectives when designing an experiential learning activity. They, in fact, represent a rather definitive attribute inventory for defining the desired competencies of a graduate engineer."]

Figure 7: Skills and Attributes for a Professional Engineer
The implications for engineering design in the above is that students cannot be left on their own and need the guidance and motivation of lecturers with a commitment to the subject area who can generate enthusiasm and a positive attitude in the students. Ramsden (quoted above) found that it was essential, in engineering, to pay much more attention to factual and procedural detail, particularly in the early stages of mastering a topic. He also found that a deep approach is necessary for a firm basis of prerequisite knowledge [Marton, 1984, p218]. So, the success of a design course may hinge on the strength of the basis of knowledge in other subjects in an undergraduate programme.

What, then, are the abilities that a designer - the problem solver - is required to possess? Ausubel and Robinson [1969] quote ten process factors (ibid., p.520) that influence successful problem solving as deduced by Bloom and Border in 1950. Briefly, they are:

'Decisiveness, focus on problem, application of knowledge that is relevant, active and vigorous process of search, careful and systematic approach, follow through to logical conclusion, attitude towards reasoning is positive not fatalistic, self confidence, objective and impersonal and overcome negative transfer effect of interfering set.'

These factors match closely the objectives listed by Harrisburger et al [1976] shown in Figure 6 and relate to the cognitive structure of the individual.

Simon [p.127, 1981], in conclusion to a discourse on learning says that human cognition is both simple and complex. He says:

'.... The inner environment, the hardware is simple. Complexity emerges from the richness of the outer environment, both the world apprehended through the senses and the information about the world stored in long-term memory. .... . Finally there are the learning and discovery mechanisms that permit the system to adapt and gradually
increase effectiveness to the particular environment in which it finds itself....becomes adept in dealing with highly specialised environments ...... the very prototype of the artificial.'

The above statement taken in the context of Lukasiewicz's views on ignorance explosion [1972] could lead to the belief that only the exploitation of biosciences could the 'biological ceiling' of man be lifted to a level where he can cope with the problem created by the 'naturally evolved man' - otherwise the mechanical man is the answer. The naturally evolved problems of the future could well be the ones created partly by engineering designers today. This requires the engineering designer to look at problems holistically with a sense of contributing to technological history.

With this concept of viewing a problem as whole, the Gestalt (a German word meaning 'whole') doctrine is interesting to the engineering design educator. Gestalt emphasises the 'structural quality of the way in which we perceive, think about, and feel, the world around us'. This structural quality is wholeness. Therefore, Gestalt psychology is also of some relevance in engineering education.

However, one of the main difficulties in applying Gestalt theory to engineering problems is that the current problems researched are of a particular nature - geometric, algebraic, mathematical. Engineering problems have a different structural characteristics [Marton et al, p127, 1984]. Another difficulty is that in Gestalt the focus is always on the problem and the student's perception of it. Wertheimer [1959] describes problem solving as:

'.... a partial field within the general process of knowledge and insight, with the context of a broad historical development, within the social
situation, and also within the subject's personal life' (p.240).

Gestalt theorists agree that past experience will facilitate solutions to problems - only when insight of previous experience is organised and applied to current problem. Further, insight is more likely when the problem is so arranged that all necessary aspects are open to observation. These statements are based on the observations Kohler made with apes.

The two chief competing alternatives to Gestalter's approach to problem solving are formal logic and association theory. Even these 'are limited to encompass what actually happens when an individual confronted with a problem finds a sensible solution' [Bower, p.321. 1981].

From the work of the many educational psychologists quoted above and their published results it is clear that the complex mental skills required in engineering design may be well served by theories relating to the cognitive domain. Therefore, for the purposes of this research work these theories seem more relevant for the education of engineers since engineering design is essentially a problem solving activity [Sheldon, 1984]. Furthermore, cognitive interpretations are more useful in problem solving and allow for the 'power and flexibility of human intellectual processes and the way in which people deal with complex problems' [Hill, p. 26-27, 1980].

It is also clear that the skills listed by Harrisburger in his study of experiential education in engineering relate closely with requirements of professional practitioners. This list is also extensively referred to mainly in the context of design curriculum development using the professional practitioner's input of information.

While the boundary between knowledge and skill is subtle [Simon,
plIO, 1981], the curriculum must base the development of skills on the knowledge already gained by the student. This is a continuum and therefore the skills developed will be increasingly sophisticated.

An unfortunate situation is that very little research work is carried out into engineering design methodology by practicing engineers themselves. One such research paper concludes that engineering design is seldom a logical progression towards an optimum solution [Tebay, 1984] and often external forces over which the designer has no control are present.

In his observation of decisions made during the designs of three different artifacts Tebay noted that the designers evolved several methods of systematic design. These appeared to have, according to Tebay's findings:

‘evolved as the designer's personal methodology rather than the formal application of published techniques.’[p95]

Tebay goes on to say that:

‘......any comprehensive model of design decision making has to develop from the field of systematic design, system engineering and relevant aspects of the behavioural sciences and that this would lead to a better understanding of the design process rather than in the formulation of a model of design decisions.’[p95]

In conclusion, the education of an individual to attain some degree of professional engineering design competence has two dimensions. The fundamental and initial dimension involves the core-competence aspect of the student acquiring discipline knowledge and the development of an aptitude for engineering judgment, technical problem-solving, critical thinking, and creativity. This is cognitive competence. Theoretical and empirical underpinnings of these related to professional education are looked at in some detail in Chapter 4.
The second is the identity of the professional which provides the confidence for effective practice within the framework and values of the society he lives and works in. This important aspect is also addressed in detail in Chapter 4.

Prior to this, however, the research looks at the real world of the engineer to help develop an authentic skills list that can be used in curriculum design.
Chapter 4
Paradigm for a Professional Engineer

Introduction

The work of Tebay et al. (1984) is indicative of the complexities encountered in the compilation of a taxonomy of objectives for the education and training of a professional engineer. These objectives, by definition, are the basis of curricula that will ‘form’ the beginner in the profession to the level acceptable to the profession. Therefore, the aim of the curricula must be essentially, though not wholly, the development of skills and attitudes as perceived to be necessary by the practicing professional. The curricula must also take into account the beginner characteristics and develop the skills of the profession starting from this fundamental base and building on it.

Methodology

1. Overview

In developing a paradigm for a Professional Engineer two separate methods were adopted in this study during the initial stages. These were basically opinion seeking and provided qualitative information. They were:

i) a descriptive postal questionnaire survey for the professional practitioner's views and opinions (this chapter) and

ii) concept mapping techniques to elicit student's views and characteristics (Chapter 5).

Further, a literature search was carried out to develop theoretical and empirical underpinnings for the professional characteristics for an engineer (Chapter 6). These were compared with the result of the survey (Chapter 4) and concept mapping of students (Chapter 5). A comprehensive skills audit was then developed. Chapter 6 describes in detail the
evolution of this final model. This model was adopted for the development of a curriculum for a professional engineering designer (Chapter 7).

2. **Professional Practitioners Survey**

One obvious source for information about the skills and attitudes necessary for professional design engineers - a special group of professional engineers - is the practicing engineer himself.

This information could be obtained by observations at work, interviews or self-reports of the practicing engineering designer. The ideal process of collecting this information is a combination of the three methods suggested - also perhaps in the sequence as quoted above.

This procedure involves the researcher being physically present with the professional practitioners during their working hours for a number of days making a note of all activities carried out. This close observation, recording, and subsequent analysis will result in statements that describe only the obviously observable and purely external functions of the practitioners. These recordings have to be supplemented by personal interviews of these practitioners to ascertain the underlying cognitive processes that underpin the observed functions.

However, in the Hong Kong context, where this research was carried out, the method of observation and interviews are extremely difficult to organise and expensive in terms of time and resources. Hong Kong survives by exporting its manufactured products and most professional engineers based in Hong Kong travel widely and frequently and are not always available for lengthy interviews.

Many of the duties of professional engineers entail confidentiality particularly with respect to new product design and development. Some are involved in sensitive jobs related to contract work and the employment and
supervision of labour. Therefore, the process of observation and interviews was considered unsuitable for this exercise.

Another fundamental need in this research was for pertinent information on practicing mechanical engineers in Hong Kong. At the time of the research, however, even basic data on numbers and location of professional engineers in the local scene - in particular mechanical design engineers - was not available in any reliable or useful form.

A starting point for obtaining this information had to be the location of possible employers of such professionals.

It was, therefore, necessary initially to identify organisations that had at least an element of engineering design in their everyday functions; get these to sponsor their own engineers to collaborate in a detailed survey and from these professional engineers obtain the relevant data. Only an intimate knowledge of the role of engineers in the industries in Hong Kong will enable a realistic foundation to be built on which a detailed engineering design course syllabus could be based.

The syllabus developed must also be fairly flexible to adapt and cope with new technologies, innovations and discoveries in science and engineering. Building in such flexibility requires an overview of corporate long term plans. This information had to be elicited from employers of professional design engineers.

3. Postal Questionnaires

The initial set of information required from employers was basically factual. Hence it was considered adequate to use a mailed questionnaire type of survey. Questionnaires contain printed form of structured questions together with spaces for filling in responses. They are often used in
surveys (administered to a statistically significant number of subjects) or as a record of information about an individual or a group.

Leedy [p76, 1980] defines the descriptive survey or normative survey method as a method appropriate for data derived from simple observational situations, whether physically observed or through questionnaires or poll techniques. Normative survey methods are used in technological forecasting [e.g. Scott, 1985] beginning with a consideration of the likely future structure and needs of society; and then consider the developments necessary to create that structure and meet those needs.

This descriptive survey method is probably the most used and most criticized of all data gathering devices. Cohen's summary [p292, 1986] of relative merits of subject interviewing compared with questionnaires is modified to include the relevant local influences as shown in Figure 8.

In the case of this exercise in Hong Kong some points in favour of such a type of survey are:

- the compactness of the geographic area concerned
- the efficient postal and telephone system
- close liaison between employers and educational institutions
- a single professional body representing all engineers and

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Figure 8: Interviews vs Questionnaires - relative merits
the general willingness of employers to cooperate in this work.

According to Fox [quoted in Scott, p68-69, 1985] descriptive and questionnaire type of survey make no judgements, no statements of quality, no evaluations; it only describes. Fox goes on to say:

'If the researcher believes the answer exists somewhere, at present, he uses the survey approach. In this approach we seek to cast light on current problems by a further description and understanding of current conditions. In other words, we seek to answer our research question through a data gathering process that enables us to describe the present more fully and adequately' [ibid., p31]

The greatest difficulty underlying any attempt to survey of professional engineers is to define what is meant by a professional engineer and to convert this to a sampling procedure. One approach is to take the function as a defining characteristic - i.e. anyone who does a certain kind of a job is regarded as an engineer, irrespective of his qualifications. Another approach is to use qualifications as the basis for definition, regardless of the work done by the individual.

A combination of these two approaches is also possible - an engineer is one who has certain qualification and is in appropriate employment. However, definitions in terms of function and qualifications do not come to the same thing. Since this survey is aimed basically to enhance the education of engineers, the qualifications characteristics have been taken as more important in defining a professional engineer (see 'p60).

The survey set out more to elicit evidence rather than data. The questionnaire was structured to provide both quantitative as well as qualitative responses. In a not too dissimilar situation, Roizen & Jepson [1985], while looking at employer's expectations of higher education, used
the questionnaire survey type of data collection (quantitative) and came to the conclusion that they were 'fortuitous' in the responses received from employers - the responses were both quantitative and qualitative.

The questionnaires were not fashioned on any one single package but were an adaptation of various manpower survey procedures used in the UK [Berthoud, 1980; CEI, 1975] and Singapore [1971, 1977]. In developing these questionnaires and their sequence it was always considered that the main purpose of the exercise was to establish the skills that were perceived to be necessary for a practicing engineering designer so that this information could be available in curriculum development and/or update.

Each questionnaire was reviewed and edited to eliminate, as far as possible, any overlapping and non-discriminating items. Initial formats were also circulated to senior staff of the Mechanical Engineering Department for views and opinions. Staff and expertise in the Hong Kong Polytechnic's Educational Technology Unit were also consulted during the preparation of the three sets of questionnaires. Modifications were made where necessary and all pilot surveys were done using these resources.

The survey was carried out in English as most of the local professional engineers have a good command of the language.

4. Details of survey

The survey was carried out in three progressive stages. While individual corporations were contacted directly it was considered prudent, with respect to local culture and customs, not to approach employees directly but rather have suitable senior engineers nominated by the organisations. Many organisations were contacted by telephone in the first instance. These were essentially organisations that had close contact with the Mechanical and Marine Engineering Department of the Hong Kong
Polytechnic over many years of collaboration in projects and student placements for industrial training.

A list of all organisations contacted initially for the survey is given in Appendix A.

4.1 Stage 1

This basically was a probe into industry in Hong Kong to identify organisations that were able to provide the necessary data needed and had the resources to do this. The survey set out to:

a) to obtain details on the nature of work carried out by the organisation;

b) to get an estimate of number of employees;

c) to ascertain if design was a required function; and

d) to confirm participation in a detailed survey.

A complete copy of the documents sent to individual organisations is given in Appendix B.

4.2 Stage 2

The purpose at this stage was to obtain the details of corporate anatomy and general views on the design function - past, present and future. The information requested was on numbers and types of graduates; professional engineers employed; design function details; future plans; and nomination of professional engineers from within the organisations to take part in the next stage of the survey - the detailed survey.

It was important at the start of this stage to gain the confidence of the organisations and the senior staff in these. Initially contact was made with the nominated person from each of the participating organisations through the telephone. This initial contact confirmed the view that Hong
Kong industries were in the process of rapid development, and, while the importance of the professional engineer was accepted, it became obvious that there was very little information readily available on their numbers, types, education, training, function and role in industry.

Employers were, in general, ready to take part in this exercise because they saw in it a potential usefulness in their future corporate planning and decision making areas. In many cases it was openly admitted that this was the first time the management had looked at their manpower situation in a more formal and organised manner.

Some agreed that such information would be a 'seller' to the outside world that basically considered Hong Kong as only a trading nation with no capability in the design and manufacture of engineering products.

One concern that was expressed by many organisations was the definition of a 'Professional Engineer'. In the questionnaire for this stage the definition used was: (see also p57)

A Professional Engineer is one who satisfies one or more of the following:

i) has a degree from a recognised institution and is now in relevant employment; or

ii) is a corporate Member of the Hong Kong Institution of Engineers or an equivalent body; or

iii) has a Higher Diploma from the Hong Kong Polytechnic and/or an Associateship of the Hong Kong Polytechnic.

Since employment in Hong Kong has always been a natural attraction for mainland China graduates there are many engineers in the Territory who have qualifications gained through study in China. These qualifications were accepted so long as the engineer was in relevant professional employment. Employers were, however, asked to state these numbers in the survey.
Employers were asked to specify number of engineers working in particular in the field of engineering design. They were also requested to give numbers involved in development, research and modification work - an activity quite familiar to Hong Kong industry and in some organisations the only one.

It was anticipated that not all organisations would be into design related work. Therefore, each was requested to state work actually carried out in their own organisations if design and development was not typical. It was possible to quote more than one area of specialisation or operation.

All organisations were also asked for information relating to their design function and its history. They were also asked to state the future plans in this area. This information was considered vital to the research.

Engineering products generally are designed to some national and/or international standards. The survey also set out to identify the standards that were adopted by the various organisations in their product design and marketing.

All organisations were requested to nominate up to nine engineers for a detailed survey. The figure of nine had no significance and was chosen arbitrarily considering that there were organisations that had perhaps just one graduate engineers and others that had up to 25% of employees who were graduates. This was established in the first stage of the survey and subsequent telephone conversations with the senior engineers in the various organisations.

A complete set of documents sent to individual organisations is given in Appendix C. This included an introductory leaflet and a four page package questionnaire.
4.3 Stage 3

The subjects of this study stage were all practicing engineers (who satisfied the definition of a Professional Engineer as stated in the second stage questionnaire and were nominated by their organisations and agreed to take part in the more detailed survey. They were contacted individually and the questionnaires were mailed to each subject individually.

The main aim of this survey was to draw up a priority list of skills necessary for the professional practice of engineering design through the details of practicing engineers' views on Engineering Design as an academic subject and an appreciation of their career paths to date. This was done through questions relating to specific areas as detailed below (question numbers in the Questionnaire are shown in parenthesis).

A complete set of Stage 3 questionnaire is given in Appendix D.

4.3.1 Personal and Academic Data

a) Personal Particulars (1,2a,2b,3)

The following personal information was requested:

- Name of employer (1);
- name of subject (2a);
- age next birthday (2b);
- title/position in organisation (3);

The subject's academic pedigree was established through questions relating to the following:

b) Academic Attainment (5)

The subjects were asked to give details of levels of qualifications obtained, year in which these were awarded and the institutions they studied for these. Awards were classified into those from local (Hong Kong Polytechnic, University of Hong Kong and the Chinese University of Hong Kong); or from United Kingdom tertiary level institutions; or from North
America (USA and Canada). Provision was made for awards from other countries such as China, Taiwan, India, Singapore, Malaysia etc. also to be stipulated on the form.

The main reason for this information was to establish the geographic locations of the origins of engineers employed in industry in Hong Kong. Because of the Colonial connections with UK, it was expected that a large proportion of engineering graduates would be from the UK. The survey was also expected to highlight any shift or preference for students to study in a particular country or institution.

c) Professional Institution membership (6)

Professionals generally tend to belong to a fraternity and progress through it's grades of membership as their careers develop. Such membership would indicate professional levels of the subjects and peer group acceptance. The question was also aimed at identifying whether local or overseas bodies were dominant in this.

d) Discipline (Academic) (7)

Engineers were asked to state their areas of majoring during their academic courses. The choice was limited to the following widely accepted engineering disciplines (in alphabetical order):

- Aeronautical, Chemical, Civil, Electrical, Industrial, Marine, Mechanical, Production and Structural.

Provision was made for other disciplines to be stated in the response. Most of the subjects were expected to be in the major areas quoted above.

e) Further (13) and Continuing education (25)

It was considered important to obtain information on any further study in the form of part-time (40 Hours duration) or short courses (about 1 week's duration) that the subjects may have undertaken after graduating in
an engineering discipline. This may indicate shortcomings and imperfections in undergraduate courses and also highlight trends in technological and management techniques and practice. These could influence the content of any curricula devised for the profession.

4.3.2 Employment and Career Data

a) Name of Employer (1) and Service Period (4)

The name of employer was needed to cross check with the previous survey to ensure that participants were the nominated ones from their respective organisations. All organisations were also clearly informed that if more subjects volunteered to take part in this exercise they would be very welcome to do so and the questionnaire could be duplicated as many times as necessary.

In anticipation of such cases the information on employer was considered a necessary inclusion in the questionnaire.

The survey also established whether subjects had sufficient exposure to the organisations they were working for. Question 4 asked for the period of time the engineer had been with the particular employer. A period of 5 years or over was considered to be a reasonable period over which a subject could perceive the direction in which the organisation is moving and from whence it came. While this was not considered critical, the information would help in the analysis of views on the helpfulness or otherwise of academic subjects in everyday working life of the professional.

b) Career Details (4,8,10,11,21)

In these questions the aims were to identify the first full time job of the subjects and their current job description. This information would show whether engineers were following the traditional route starting from an apprenticeship/training scheme to subsequent professional status or that
there was no specific or particular sequence of progress through the profession. If industry was re-training graduates to meet its requirements then the curriculum in tertiary education must reflect this situation.

The list of first full time jobs descriptions was compiled from results of Employment Survey carried out by the Student Welfare Unit (SWU) of the Hong Kong Polytechnic and from analysis of local news media advertisements.

Appendix E shows some typical industry requirements for fresh graduates as presented in a local newspaper's Classified section. The details of job descriptions in these advertisements (Note: only a random sample is shown in Appendix E) produced the individual items in Questions 8, 11, 12 and 24 in the Stage 3 survey (Appendix D). For example, Sales and Marketing appear in all but one of the above questions since this appears regularly in the advertisements for engineers. Project Work, on the other hand, is a less frequent occurrence and this is reflected in this appearing only in Question 12.

Many employers looked for ability in languages - particularly English and Mandarin or Putonghua - see advertisements 2, 5, 8, 10, 12, and 16 (Appendix E). This prompted the design of Question 19 in an effort to establish the market needs for language skills in the engineer.

Some employers require a knowledge of standards - both local and international (see advertisement 15, Appendix E).

Appendix F shows the relevant section of the results of the SWU survey on the employment of Hong Kong Polytechnic graduates in mechanical engineering. The details given in the tables are self-explanatory.
It was known that some fresh graduates, particularly ones who had come through an apprenticeship and Higher Certificate in Mechanical Engineering prior to a degree, were employed directly in Supervisory and management roles, the majority were presumed to start their careers in a training or other junior positions. This presumption had to be validated.

In establishing the current work carried out by subjects, a wide choice was offered for the response. The job descriptions offered were constructed to reflect as far as possible the nature of engineering activities in Hong Kong.

Some of the findings relating specifically to the practitioners in the territory and of interest to manpower resources planners were published locally [Chandran, 1985, 1986]. In these the author pointed out that it was clear that the survey covered mainly:

"the larger and more visible organisations that are involved in engineering design. There are, however, 48992 registered establishments (end 1984) in the manufacturing sector [---]. An input from this 'smaller' group may have a significant effect on the skills identified." [Chandran, p182, 1985]

While this observation by Chandran is acceptable for the Hong Kong situation (as indeed it was made in that context), the subjects' responses from the more 'involved' organisations would certainly generate data that could be more universally applicable. In terms of engineering design and the design of engineered artefacts some of the skills identified would be similar to those required for any organisations anywhere in the world.

The job descriptions ranged from sales and marketing to design, finance and operations. Again, some of the descriptions were from the SWU surveys and from local advertisements for professional engineers.

It was considered important to determine whether subjects were
involved in creative and original work. A basic assumption in this was that if the work currently carried out by the subject could be handled by a computer, say, even in ten year's time then this work could not be classified as creative or original work. The validity of this information would be questionable if majority of the subjects did not use computers in their current work. Questions 16 and 17 catered for this aspect.

Question 25 was framed to determine the views held by subjects regarding their future and the training and further education they felt were needed in achieving their aims.

This was the only 'open-ended' question in this stage of the questionnaire survey. Practitioners were required to write briefly about their further education and training requirements that would enable them to cope satisfactorily and perform more efficiently in their current jobs. It required subjects to consider their own careers and state briefly what workskill/performance they would like to improve and how they would achieve this. The comments in this section would be essentially subjective. This question was designed to come at the end of the questionnaire so that the subject could finish the responses by declaring where he would like to progress to in his profession.

4.3.3 Views on undergraduate Curriculum

a) Rating of academic subjects studied at first degree level (9)

This was one of the most crucial and critical sections of the survey. There were many aims that dictated the structure and format of each of the elements in the question and the sequence. The basic aim, however, was to study the practitioners' views of the utility of the conventional engineering course academic units in their everyday activities at work.

This section required the participants to identify academic subjects
that were generally useful; those that were used in the immediate past and the frequency of use; and subjects that were not studied during their undergraduate period. Eighteen separate academic areas of mechanical engineering were listed for response to this question. The participants' responses were channeled into three separate parts as described below.

A working week was taken as equivalent to five working days. It was considered that participants would be able to relate the academic areas described in this question quite easily to their previous week's work and make reasonably accurate statements regarding their utility. The frequency of use of a unit over the immediate past week would help to determine its current usefulness to the professional practitioners.

It was anticipated that some of the senior engineers may not have had formal education in some of the academic areas quoted in the question such as Computer Studies and Electronics. Some may also have exercised options in the final stages of their undergraduate work and not studied all of the units listed. Provision was made to take into account of these variabilities.

Each unit was rated either as very useful, useful or not useful on a general usefulness basis. No ranking was used in the survey as it was only necessary in this question to determine the utility of each area in the professional's everyday work.

Statement on immediate use of each unit was needed to rank skills at a later stage when a professional paradigm of an engineering practitioner would evolve. This would indicate skills that are being used currently in industry locally.

If a particular unit was not studied at first degree level but was
still used in everyday work, then this would influence the choice and inclusion of elements in the curriculum for engineering design. Conversely, if a unit was studied and was not used in the immediate past or regularly, this could also influence the contents of the curriculum.

All academic units were grouped into areas of commonality. Engineering Design, for example, was grouped with Project Work and Technical Report Writing. Industrial Management was grouped with Work Study and Production Engineering. The list of academic subjects was compiled from courses over the past twenty years so that today's professionals would recognise the name and relate this and the content of the syllabus to their current work.

b) Listing of Skills for Engineers (12,14,15,18-20)

Participants were asked in question 12 to analyse their current job content and identify academic areas that they felt were either not covered or not dealt in sufficient detail and depth in their undergraduate courses. The literature survey carried out previous to this work highlighted the fact that engineering courses and curricula was in general lacking in developing management and communications skills (see Chapter 2, p18-21; & Chapter 3, p35). The responses to this will either confirm this fact or dismiss it as irrelevant in the Hong Kong context.

In another question (14) they were asked to list skills that they considered necessary and suitable for a professional engineering designer. Each participant was asked to list ten important skills in order of priority. This would enable identifying some common skills that all engineers should possess and which could help in the determination of the interrelationships between individual skills.

This would also indicate the participants' perceived current views and understanding of the engineering profession. It would also facilitate some
comparison of the practitioner's statements on the general and specific utility of individual academic subject areas and their views on what ought to be taught in degree programmes.

Questions 11 - 14 were sequenced to encourage participants to review their current work situation; relate this to deficiencies (if any) in their academic training; state whether they embarked on continuing education programmes to bridge the discrepancies and finally to have a say, albeit only theoretically, in the development of a degree programme.

Further general information was sought in terms of computer usage and access to Computer Aided Design and Manufacture systems (questions 16, 17 and 21). The aim was to establish whether modern technology was in fact being utilised and employed in the local organisations and to what level.

Since the general literature research showed a strong indication that the engineer's education lacked the development communication skills part of the survey focused on this aspect. Question 19 asked participants to rank non-technical areas such as English language, Management, the Engineer in Society (a subject traditionally taken by engineers in their progress to Corporate status in their professional institutions) and others in a priority scale.

The practitioners' tasks performed both on a daily basis and during their careers to date was to be established through specific responses to questions 22-24. Questions were self explanatory and practicing engineers would be able to respond accurately to these. The questions were again progressive in that the participants were asked to state their current work details and show their career progress in industry since graduation.

Industry in Hong Kong is very flexible and adapts to changes in the
international scene very rapidly. Consequently the nature of an engineer's role in it must also be changing. This implies that an engineer, say in the 26-45 years age group may have had a varied career with many job specification changes. Some job specification titles (taken from the local press advertisements) were offered to the participants in question 24. They were also able to add to the list based on their own experiences.

In the Hong Kong context it was necessary to establish engineering standards that were generally followed - i.e. international, local or corporate. Being a free-port, it was expected that standards from many countries would be in operation in the local industries.

Professionals recognise that their skills need to be updated frequently. The identification of specific skills that need to be updated for a professional practitioner can lead the way to preparing a realistic curriculum for the education of future generation of engineers. This is, of course, a continuum and needs to be established at frequent intervals. Any curriculum development exercise, however, must take this into account. Question 25 addressed this particular requirement.

5. Results of Survey

5.1 Stage 1

A total of 42 organisations were approached with the first questionnaire (Appendix A shows a list of participating organisations). Each of these organisations were sent a questionnaire containing nine very short questions relating to their anatomy and the nature of their work. They were asked to show their commitment to this survey by accepting (or otherwise) to take part in a more detailed exercise involving their engineers. Majority of these organisations had already been contacted by phone prior to sending the questionnaires. Of these:
33% - (14) organisations accepted and confirmed in writing or verbally to take part;

57% - (24) showed interest in the survey but were not committed; and

10% - (4) did not feel that they were sufficiently connected with design and hence were reluctant to take any further part.

The activities of the 14 participating organisations covered the following areas:

<table>
<thead>
<tr>
<th>Number of organisations</th>
<th>Main Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shipboard and marine</td>
</tr>
<tr>
<td>2</td>
<td>Building Services</td>
</tr>
<tr>
<td>2</td>
<td>Electrical and Mechanical Services</td>
</tr>
<tr>
<td>1</td>
<td>Beverage Manufacture</td>
</tr>
<tr>
<td>1</td>
<td>Land Vehicle Operation</td>
</tr>
<tr>
<td>2</td>
<td>Consumer Equipment Manufacturer</td>
</tr>
<tr>
<td>1</td>
<td>Telecommunications</td>
</tr>
<tr>
<td>2</td>
<td>Engineering Consultancy</td>
</tr>
<tr>
<td>1</td>
<td>Electronics and Optical Equipment</td>
</tr>
</tbody>
</table>

Hong Kong does not as yet have any detailed standard industrial classifications other than a broad one under the title 'Manufacturing'. In the United States, for example, the SIC (Standard Industrial Classification) numbering system is published by the Statistical Policy Division of the US Government. The SIC numbering system is used to classify all firms by activity to facilitate compilation and presentation of data. There the three thousand series numbers indicate manufacturing. The 4 digit number identifies and defines the specific industry within a sub-group.

Similar codes exist in most industrialised nations. With such details readily available, computers can be used to extract necessary up-to-date information easily. This had to be carried out manually in Hong Kong.

The positive response, however, of just over 33% of the survey sample was considered satisfactory due to one main reason. As the survey entered
the second stage it was expected that more organisations would volunteer to participate. This was anticipated because of the initial verbal support and subsequent written commitment of the local Federation of Hong Kong Industries (FHKI).

(A copy of the letter detailing subsequent active support from this Federation during the second stage of the survey together with the FHKI duplicated survey forms for Stage 2 are enclosed in Appendix G.)

All except one organisation was involved directly with design and modification of engineering components and systems.

5.2 Stage 2

Support from FHKI ensured that the Stage 2 questionnaires reached over 1000 manufacturing organisations in Hong Kong. Most of these are small scale or mainly assembly line operators and were not expected to respond to the survey. Of the 38 organisations that were identified in Stage 1 as ones involved in engineering design (and a further five that were contacted later) 22 responded (about 52%) within the time stipulated.

Table 1 shows size of organisations with 73% of the participants having more than 501 employees on their payroll. There were three organisations with over 3000 employees, one of these employing more than 10,000 staff. Over 90% or twenty of the 22 participants had more than 101 employees.

<table>
<thead>
<tr>
<th>Number of Employees</th>
<th>% of all organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 100</td>
<td>9</td>
</tr>
<tr>
<td>101-500</td>
<td>18</td>
</tr>
<tr>
<td>501-1000</td>
<td>41</td>
</tr>
<tr>
<td>1001-3000</td>
<td>18</td>
</tr>
<tr>
<td>Over 3000</td>
<td>14</td>
</tr>
</tbody>
</table>

Table 1: Number of Employees
Corporate views on Design is outlined in Table 2. The split between firms with more than 5 years or less than 5 years of design function in the organisation was a perfect one - 50/50. There were, however, some 60% of the less-than-5-years category that did not have any design function at all.

<table>
<thead>
<tr>
<th>Existence of Design function</th>
<th>% of all organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>less than 5 years</td>
<td>50</td>
</tr>
<tr>
<td>5-15 years</td>
<td>22</td>
</tr>
<tr>
<td>over 15 years</td>
<td>28</td>
</tr>
</tbody>
</table>

Table 2: Design Function in organisations

About 60% of the organisations (13 firms) stated that they expected the design function to increase over the next ten years. Only one expected this to be reduced while the remainder expected this to remain same or were not sure. The indication here is that the design activity in industry in Hong Kong is more likely to increase than not.

The total number of graduates of all disciplines employed by the participating organisations was 1287. The distribution of graduates among the respondents is shown in Table 3.

<table>
<thead>
<tr>
<th>No. of Graduates</th>
<th>% of responding organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>All disciplines</td>
<td></td>
</tr>
<tr>
<td>(%age of total employees)</td>
<td></td>
</tr>
<tr>
<td>0 - 5</td>
<td>64</td>
</tr>
<tr>
<td>6 - 10</td>
<td>14</td>
</tr>
<tr>
<td>11 - 20</td>
<td>14</td>
</tr>
<tr>
<td>over 20</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 3: Distribution of Graduates

Among these graduates the proportion of engineering graduates to those of other disciplines was more than half in 80% of the participating
organisations. 63% of engineering graduates were employed in design related functions. Table 4 shows details of this breakdown.

Of these graduates nearly 60% (761) were the product of local institutions - the University of Hong Kong; the Chinese University and the Hong Kong Polytechnic. Table 5 shows the origin of qualifications of the graduates. Professional engineers preferred to belong to overseas professional bodies rather than the local ones.

<table>
<thead>
<tr>
<th>%age of Engineering Graduates (of total number of Graduates in firm)</th>
<th>%age of participating organisations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 20</td>
<td>18</td>
</tr>
<tr>
<td>21 - 50</td>
<td>0</td>
</tr>
<tr>
<td>51 - 60</td>
<td>14</td>
</tr>
<tr>
<td>61 - 80</td>
<td>36</td>
</tr>
<tr>
<td>over 80</td>
<td>32</td>
</tr>
</tbody>
</table>

Table 4: Proportion of Engineering Graduates

It must be stated here that Membership of the local Hong Kong Institution of Engineers has recently been recognised by the Government of Hong Kong as mandatory for posts within the civil service and this is likely to make this local body more attractive for engineers to belong to. This is likely to affect the figures in Table 5.

<table>
<thead>
<tr>
<th></th>
<th>Academic (1st Degree or equivalent)</th>
<th>Professional (Corporate Membership)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local*</td>
<td>60%</td>
<td>14%</td>
</tr>
<tr>
<td>UK</td>
<td>18%</td>
<td>70%</td>
</tr>
<tr>
<td>US</td>
<td>12%</td>
<td>14%</td>
</tr>
<tr>
<td>Others</td>
<td>10%</td>
<td>2%</td>
</tr>
</tbody>
</table>

(* Local - Hong Kong University; Chinese University of Hong Kong; and the Hong Kong Polytechnic)

Table 5: Origin of Qualifications - All Graduates

All organisations followed British Standards in their nature of work.
Many also used ISO and American (US) Standards. Over 80% used computers in their daily work and 50% used both mainframe and micro computers.

In response to volunteering for the next stage of the exercise, all participating organisations nominated at least one senior engineer from their firm. Finally a total of 51 practicing professional engineers were registered for the next stage of the investigation.

5.3 Stage 3

Personal and Academic Particulars

a) Personal Particulars

Of the 51 engineers who were sent the Stage 3 questionnaire, 42 responded within the time stipulated - a response rate of 83%. The participants were mainly (86%) between 26-45 years of age. This age group implies industrial experience of between four and twenty years. This would be an appropriate group to solicit information on the skills required in a professional engineering designer.

b) Academic Particulars

They were mostly educated locally (60%) and were mainly from the mechanical/production discipline (69%). Tables 6 and 7 show the age group and academic qualifications source of the respondents.

Only 25% belonged to local professional bodies. Majority (60%) were members of overseas bodies. This correlated closely with the figures for all the engineering graduates employed in the participating organisations (see Table 5). There were, however, almost twice as many in this survey who belonged to the local professional body (25% compared to 14% for all engineers).

It was important to establish this link with the local education scene.
in order to relate any statements made later by the participants to the courses conducted here and to the needs of industry in Hong Kong.

It is clear that the majority are of local pedigree and therefore their data is relevant in the development of any curriculum for institutions here.

c) Employment and Career Details

Majority of the participants moved straight to a post in industry after graduating without any training or apprenticeship. Only 26% had any training or apprenticeship. Only 26% had any training or apprenticeship.

<table>
<thead>
<tr>
<th>Age in years</th>
<th>% age of participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Below 25</td>
<td>10%</td>
</tr>
<tr>
<td>26 - 35</td>
<td>76%</td>
</tr>
<tr>
<td>36 - 45</td>
<td>10%</td>
</tr>
<tr>
<td>Over 45</td>
<td>4%</td>
</tr>
</tbody>
</table>

Table 6: Age Distribution

<table>
<thead>
<tr>
<th>Academic (1st Degree or equivalent)</th>
<th>Professional (Corporate Membership)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local*</td>
<td>60%</td>
</tr>
<tr>
<td>UK</td>
<td>12%</td>
</tr>
<tr>
<td>US</td>
<td>14%</td>
</tr>
<tr>
<td>Others</td>
<td>14%</td>
</tr>
<tr>
<td></td>
<td>25%</td>
</tr>
<tr>
<td></td>
<td>60%</td>
</tr>
<tr>
<td></td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>6%</td>
</tr>
</tbody>
</table>

Table 7: Origin of Qualifications - Participants

<table>
<thead>
<tr>
<th>Job Titles</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Training</td>
<td>22</td>
</tr>
<tr>
<td>Apprenticeship</td>
<td>4</td>
</tr>
<tr>
<td>Design</td>
<td>16</td>
</tr>
<tr>
<td>Research/Development</td>
<td>12</td>
</tr>
<tr>
<td>Production/Manufacture</td>
<td>10</td>
</tr>
<tr>
<td>Sales/Marketing</td>
<td>4</td>
</tr>
<tr>
<td>Administration</td>
<td>4</td>
</tr>
<tr>
<td>Maintenance</td>
<td>6</td>
</tr>
<tr>
<td>Test/Inspection</td>
<td>6</td>
</tr>
<tr>
<td>Others</td>
<td>16</td>
</tr>
</tbody>
</table>

(* % age of participants)

Table 8: First Job Details

77
formal engineering training as their first experience in industry immediately after graduating. 38% went into design, research, development and production related posts as their first job. Table 8 illustrates the variety of first jobs held.

The first job details indicates that, next to training, design is the most common first job held by engineering graduates. This is more significant if research is added to this. Considering academic subject definitions and details, research activity is the closest to design in terms of describing in a curriculum - certainly nearer than any of the core subjects.

Most engineers, in their subsequent careers, have been involved in various aspects of design - specification writing and interpreting; preliminary and detail design; checking designs and, to a lesser extent (26%) in strength analysis. Table 9 illustrates the range of roles during the career of the participants.

<table>
<thead>
<tr>
<th>Role/Activity</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary Design</td>
<td>70</td>
</tr>
<tr>
<td>Detail Design</td>
<td>53</td>
</tr>
<tr>
<td>Checking Design</td>
<td>53</td>
</tr>
<tr>
<td>Specifications</td>
<td>95</td>
</tr>
<tr>
<td>Strength Analysis</td>
<td>26</td>
</tr>
<tr>
<td>Production/Manufacture</td>
<td>86</td>
</tr>
<tr>
<td>Research/Development</td>
<td>60</td>
</tr>
<tr>
<td>Sales/Administrative</td>
<td>56</td>
</tr>
<tr>
<td>Management/Marketing</td>
<td>56</td>
</tr>
<tr>
<td>Maintenance/Operations</td>
<td>62</td>
</tr>
</tbody>
</table>

(* % age of participants)

Table 9: Career Activities Details

d) Academic Views

The general usefulness of engineering subjects rated by participants ranked the individual academic units as shown in Table 10.
In Table 10, column I gives the consensus of priority given to the general utility of each unit as perceived by the participants. The ranking was arrived at by totalling the first column responses in Question 9 and then arranging these in order. Although there were three possible levels of response for this question (see Appendix H for levels and actual tallies of responses to this question) and further sub-divisions in each level, only

<table>
<thead>
<tr>
<th>Academic Units</th>
<th>Ranking of</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Engineering Design</td>
<td>3</td>
</tr>
<tr>
<td>Computer Studies</td>
<td>6</td>
</tr>
<tr>
<td>Project Work</td>
<td>5</td>
</tr>
<tr>
<td>Mathematics</td>
<td>2</td>
</tr>
<tr>
<td>Technical Subjects</td>
<td>7</td>
</tr>
<tr>
<td>Engineering Drawing</td>
<td>1</td>
</tr>
<tr>
<td>Technical Writing</td>
<td>2</td>
</tr>
<tr>
<td>Management</td>
<td>2</td>
</tr>
<tr>
<td>Production Engineering</td>
<td>4</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>3</td>
</tr>
<tr>
<td>Electronics</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 10: Academic Units - Usefulness Priority

1 - General Usefulness ('very useful')
II - Current Usefulness ('more than once')
III - Participant Nominated (Response to Question 14)

the column for 'very useful' was tallied. The other two columns, for 'useful' and 'not useful' were included in the questionnaire to enable participants to have a choice. This also helped to eliminate the situation where

'the person (participants) can attempt to put on a facade of honesty, vigor and assertiveness, or sweet reasonableness if this is what the test situation seems to call for. For this reason it is often necessary that the purpose of the test be somewhat camouflaged, that the procedures be indirect ...' [Thorndike, p492, 1977]

Similarly, only the last column tallies for the section on immediate utility (used in the immediate past five working days of the participants)
were counted i.e. the column titled 'more than once'. The 'once only' and the 'never' columns were ignored in the analysis for the same reasons as above. This total was then ordered and ranked as indicated against each subject in column II of Table 10.

Appendix J shows the summary of tally counts for the various sections of Question 9 of Survey Stage 3. The table shown contains all the details that were recorded from the participants. However, only data from columns B and H were analysed further.

To emphasise the relative weighting given the subjects, two pie charts (Figures 9 and 10) illustrate the proportion of total tallies in each subject area.

It is clear that some of the core technical subjects (like Strength of Materials, Thermodynamics) are not rated high whereas the management, interpersonal and design skills (as in subjects like Management, Design, Project Work) are rated high.

Aeronautics, for example, was never used by any of the participants generally while only one participant indicated that Design was not generally useful. This is clearly observable in the chart in Appendix J detailing the original questionnaire with the total responses for each section of Question 9.

Comparing the utility of subjects on a general and immediate basis, there appears to be a similarity between the two. This is illustrated graphically in the bar chart shown in Figure 11 and in a line/graph plot in Figure 12 - to show more graphically that the very useful and the 'used more than once' subjects have a similar frequency distribution curves. This similarity or relationship can be statistically analysed to assess the level of correlation.
Figure 9: Pie Chart of Subject Utility - 'Very Useful'

- drawing: 11.7%
- maths: 9.2%
- s.o.m: 3.1%
- mom+vib: 3.1%
- control: 3.1%
- elect: 8.6%
- electronic: 7.4%
- comp: 6.7%
- des: 8.6%
- proj: 7.4%
- tech writ: 9.2%
- mgt: 9.2%
- work study: 3.1%
- prod eng: 8.0%
- fluids: 1.8%

Figure 10: Pie Chart of Subject Utility - 'more than once'

- drawing: 9.6%
- maths: 11.4%
- s.o.m: 2.6%
- mom+vib: 1.3%
- control: 3.1%
- elect: 7.9%
- electronic: 7.9%
- comp: 6.1%
- des: 8.3%
- proj: 10.0%
- tech writ: 8.7%
- mgt: 10.0%
- work study: 3.5%
- prod eng: 7.9%
- fluids: 1.7%
Figure 11: Bar Chart of Subject Utility
Figure 12: Line/Graph plot of Subject Utility Data

Subject Utility - participant's priority

frequency

subjects

dwg math som mom dyn cntl elec enc comp des proj rep mgt ws prdn fluids lhm aero

very useful  used > once
An appropriate test for such non-parametric data analysis is a test for determining the correlation between variables (generally referred to as Spearman Rank Correlation). The power efficiency of this test compared with a parametric test is 0.91 [Lipson & Sheth, p249, 1973].

This correlation test involves ranking two variables in increasing algebraic order. The difference between the ranks is then calculated and is used to determine a statistic \( r_s \), which is related to the correlation. Value of \( r_s \) varies from -1 to +1, which corresponds to the perfect inverse relationship to the perfect direct relationship. By squaring this value an important relationship is obtained. For example, if \( r_s \) is 0.9, then \( r_s^2 \) is 0.81. Thus, 81\% of the variation of either variable is explained by its correlation.

The procedure and equations adopted in this investigation are as described by Lipson [Lipson, p-249, 1973].

The data that is used in the correlation analysis appears in Table 11. Subjects are listed in no particular order - they were listed as they appeared in responses to Question 14 in the Stage 3 survey.

For the data in Table 11, using the Spearman's equation (1), the following correlation factors evolve:

- Correlation ratio, \( r_s^{xy} \) for X and Y = 0.93
- Correlation ratio, \( r_s^{xz} \) for X and Z = 0.85
- Correlation ratio, \( r_s^{yz} \) for Y and Z = 0.75

Since the absolute values approach 1, it can be concluded that there is a definite correlation between what the professional engineers find 'very useful' in their everyday practice and their nominated skills for a first degree course.
|   | Subjects          | X  | Y  | Z  | X_i | Y_i | Z_i | |d_{iX}| |d_{iZ}|
|---|------------------|----|----|----|-----|-----|-----|--------|--------|
| 1 | Drawing          | 19 | 22 | 23 | 1   | 4   | 4   | 3       | 3       |
| 2 | Mathematics      | 15 | 26 | 22 | 3   | 1   | 5   | 2       | 2       |
| 3 | SOM              | 5  | 6  | 13 | 12  | 13  | 9   | 1       | 3       |
| 4 | MOM              | 4  | 3  | 10 | 14  | 15  | 13  | 1       | 1       |
| 5 | Dynamics         | 1  | 0  | 10 | 16  | 17.5| 13  | 1.5     | 3       |
| 6 | Control Engg     | 5  | 7  | 10 | 12  | 12  | 13  | 0       | 1       |
| 7 | Electrical       | 14 | 18 | 14 | 5.5 | 8   | 7   | 2.5     | 1.5     |
| 8 | Electronics      | 12 | 18 | 12 | 8.5 | 8   | 10  | 0.5     | 1.5     |
| 9 | Computers        | 11 | 14 | 25 | 10  | 10  | 3   | 0       | 7       |
| 10| Design           | 14 | 19 | 26 | 5.5 | 6   | 2   | 0.5     | 3.5     |
| 11| Projects         | 12 | 23 | 11 | 8.5 | 2.5 | 11  | 5.5     | 2.5     |
| 12| Report Writing   | 15 | 20 | 14 | 3   | 5   | 7   | 2       | 4       |
| 13| Management       | 15 | 23 | 29 | 3   | 2.5 | 1   | 0.5     | 2       |
| 14| Work Study       | 5  | 8  | 4  | 12  | 11  | 16.5| 1       | 4.5     |
| 15| Prodn Engg       | 13 | 18 | 14 | 7   | 8   | 7   | 1       | 0       |
| 16| Fluids           | 3  | 4  | 5  | 15  | 14  | 15  | 1       | 0       |
| 17| Thermo           | 0  | 1  | 4  | 17.5| 16  | 16.5| 1.5     | 1       |
| 18| Aeronautics      | 0  | 0  | 0  | 17.5| 17.5| 17  | 0       | 0.5     |

n - number of subject (total of 18)
X - 'very useful'
Y - 'used more than once'
Z - participants nominated tally count
X_i - X algebraic rank order
Y_i - Y algebraic rank order
Z_i - Z algebraic rank order
* - difference between X and Y ranks
@ - " " X and Z ranks

Table 11: Data for Spearman's Rank Correlation
With these values for the correlation ratio in equation (2) tests for significance can be carried out. Values for $t$ in the three cases above are, respectively $10.457$, $6.394$ and $4.468$. Referring to standard tables [Lipson, p435, 1973], for a sample size of 18 and a confidence level of 0.0005, the value for $t$ is $4.015$.

Therefore, since the calculated values of $t$ for three case are all greater than the standard value, it can be concluded that a confidence level of 99.95% can be attached to the three sets of information that have been gathered from engineering practitioners.

The interpretation of the data generated and (from this data) the development of a list of skills necessary for a professional engineer as perceived by the practitioners is discussed in Chapter 6.
Chapter 5

Concept Mapping - Review and Strategy

1. Review of Related Research and Literature

Our perception of the world and our actions are determined by concepts and their interrelationships. This is a dynamic process and in today’s world new knowledge has to be assimilated almost on a continuous basis. In engineering and technology the rate of change is, if not more, at least as rapid as in most other disciplines. New concepts need to be absorbed as science and technology march on.

According to Einstein [p471, 1947] there are two ways of regarding concepts, both of which are necessary to understanding. The first is that of logical analysis. It answers the question, How do concepts and judgement depend on each other? In answering it we are on comparatively safe ground. It is the security by which we are so much impressed in mathematics.

Secondly, concepts can acquire content only when they are connected, however indirectly, with some sensible experience. This reference to sensible experience does not de facto imply that the concepts are deducible from them in any logical sense. Einstein [1947] goes on to say:

‘But no logical investigation can reveal this connection; it can only be experienced. And yet it is this connection that determines the cognitive value of systems of concepts’ [p471]

In recent years, however, the impact of cognitive psychology [Ausubel, 1978; Novak, 1984; Moreira, 1979] has highlighted the usefulness of techniques such as concept mapping and heuristic devices in determining the cognitive structure of learners.

Ausubel [1968, et al., 1978] contends that one’s cognitive structure is hierarchically organised and Novak & Gowin [1984] have based their concept
mapping strategy on this theory. Concepts are arranged in a super- and sub-
ordinate fashion hierarchically. Novak [1984] defines concepts as a
regularity in events or objects designated by some label. Culture is the
vehicle, according to Novak [p4, 1984], through which children acquire
concepts. He says:

‘By the time children begin school they have acquired a
network of concepts ....... that play a crucial role in
subsequent school learning’ [p5]

As children grow and acquire new concepts they learn to relate and
connect the new ones to some of their previous experiences. Therefore, in a
learning situation conscious effort is required for a student to relate
such new knowledge to knowledge previously acquired. Ausubel [et al.,1978]
states in his Preface to the book:

‘The most important single factor influencing learning
is what the learner already knows. Ascertain this and
teach him accordingly’

What an undergraduate knows about the profession he is to enter and
the skills needed for competency in it have generally not been considered
when curriculum and courses are developed. This initial concept held by the
beginner is vital, as Ausubel has pointed out, if subsequent education is
to be assimilated and effective. One technique that can externalise this
initial knowledge is concept mapping.

Concept mapping is based on Ausubel’s learning theory [Ausubel et al.,
1978] which proposes that concept and propositional learning is the basis
on which individuals construct meaning. Novak , however, points out that:

‘How accurately concept maps represent either the
concepts we possess or the range of relationships
between concepts we know (and can express as
propositions) can only be a conjecture at this time’
[1984, p17]

Novak goes on to conclude that concept mapping can be a creative
activity and may even foster creativity. These conclusions are drawn from the possibility that new concept relationships may be developed in the process of drawing up concept maps.

While concept mapping may have evolved through the application of the technique in specifically primary and secondary school settings, it appears to be a versatile and effective strategy which can be adapted for use with almost any subject matter and its application is not limited to academic or school-oriented material [Loncaric, p2, 1986]. It is no longer a purely pedagogical tool for teaching and learning events.

Concept mapping is a particularly appropriate tool for examining the student's concept organisation since concepts are presented in a graphical form. It requires students to structure concepts, organisation and their interrelationships from memory.

A very important factor in such a process is that the information so displayed is from the student's own perspective rather than from a framework imposed by the lecturer or test-maker. It reveals the cognitive structure and views (moulded by his own experiences and knowledge) held by the student on a particular topic.

From Ausubelian learning theory [1968, 1969, 1978, 1979], we can expect that concept maps will have the best psychological organisation when they are constructed hierarchically - with the most general, more inclusive concept at the top and the less inclusive concept at the subordinate levels.

Concepts, however, do not exist in isolation and are dependent on many others for any understanding or meaning. Ault [1985], researching into the application of concept mapping techniques as a study strategy in earth
sciences, says:

'The tactic holds promise for many phases of science instruction and study. ... Concepts signify patterns in events and connect experiences that are otherwise unrelated.' [p38]

Loncaric [1985] stresses the flexibility of the technique and hence the broad potential for use in education [ibid., p35]. The process, however, requires complex mental activity. As Novak [1984] has pointed out

'Until further advances take place in our understanding of the neurobiology of memory process, we are limited to models that merely describe the psychological processes that operate in learning and recall of meaningful material.' [p17]

While concept mapping is no panacea, there are no real restrictions on its applications and use. In relation to its general use, Ault's [1985] cautions are worth noting. He concludes from his research that concept mapping may be most useful in the context of attempting to grasp difficult new abstractions; maps heighten awareness of a need to know more; but in non-supportive settings tolerance for concept mapping may fade away very rapidly. The important requirements for the successful application of this technique, according to Ault [1985] are:

'... clarity of meaning and integration of details. Mapping exercises require one to think in multiple directions and to switch back and forth between levels of abstraction.' [p39]

Ault [ibid., p42] suggests the use of concept mapping in the field of knowledge representation and interview analysis. In the former case the effort is made to map the patterns of meaning governing expert thinking in a narrow domain. This could be the student's view of a professional engineer.

In the latter case, concept mapping is used to represent student's conceptions rather than personal interviews. In either case the student is reporting graphically from his own experiences and knowledge. He is led
away from rote learning and towards true understanding of concepts and their relationships.

Another advantage in concept mapping in relation to this investigation is that it permits variation in right answers. There are many possible patterns capable of connecting concepts. Maps generated by students can be compared with expert knowledge. In the case of this study, student knowledge can be compared with that of the professional practitioners'.

As stated earlier (Chapter 3, p.40), West [1984] suggested concept mapping as a technique to integrate and differentiate symbolic knowledge in a learner. As a beginning professional, the undergraduate engineering student possesses some concepts of the skills and attributes of practitioners in his profession. This investigation was carried out to externalise these concepts. The literature research suggests that concept mapping is an appropriate tool for this purpose.

Given some training in the preparation of concept maps, these students may be able to present graphically their concepts of a professional engineer. This readiness in students is crucial in establishing their a priori knowledge in terms of skills requirement for the professional practitioner.

Loncaric [1986], in studying the effect of concept mapping learning strategy upon acquiring social studies concepts and deciding on the number of maps students need to develop in order to attain a reasonable degree of proficiency, concluded that:

'..... after the third concept map the students had mastered the necessary concept mapping skills and, therefore, improvements would be minimal .....' [p48]

If this is acceptable for primary students, it is reasonable to assume
that students in the mechanical engineering stream at the Hong Kong Polytechnic (entrance normally based on two ‘A’ levels minimum) would also be proficient at the third attempt at concept mapping their knowledge domain.

For the purposes of this study, concept mapping was defined as a process by which individuals may illustrate their perceived views (of a professional engineer) by letting their thoughts flow freely around the concept; then hierarchically organising these associations; and indicating the links and interrelationships between these.

Some typical examples of concept mappings found in the literature research are shown in Appendix K with a detailed presentation of one of the maps. These include works of Ault [p41, 1985]; Brody [p111, 1985]; Cliburn [p106, 1985]; Loncaric [p51, 1986]; Novak [p16, 1984].

2 Strategy

2.1 Sample Group for Concept Mapping Training

The sample group for training in concept mapping technique was the final year Bachelor of Engineering (Honours) degree in Mechanical Engineering students - 30 students - (academic year 1987/88).

These were considered eminently suitable because:

a) they were more mature than students in the earlier years of the course; and

b) they had already been exposed to a 12 month industrial attachment in their 3rd year of the four year course (sandwich programme) thereby possessing some observed and direct knowledge of professional engineering skills.

2.2 Training in Concept Mapping Technique

The process of constructing a concept map is easy to understand but difficult to execute. Basically a concept map is a two dimensional graphical representation of concepts and their interrelationships
hierarchically ordered (see examples in Appendix K). The first dimension, the vertical dimension, represents the hierarchical order with the most general and inclusive statement at the top and the most specific and exclusive at the bottom.

The second dimension, the horizontal dimension, shows the propositions and the cross links between the concepts. These relationships are indicated by both clustering of subordinate concepts under their more general subsumers and by lines linking concept names. It is at this point that the structure of the subject matter - at least as perceived by the constructor - becomes evident [Cliburn, p32, 1985].

There are currently many published methods of concept mapping. Novak [p25-35, 1984] suggests various separate strategies for different grades - from grade one through to college level. Brody [p75, 1985] suggests a simple four step method of constructing a concept map. This involves the identification of the concept to be mapped; placing the most inclusive concept at the top; adding more specific concepts under the appropriate more general concept; and linking and labeling concepts succinctly as the final step.

A stepwise method for constructing concept maps is suggested by Ault [1983 (quoted in Cliburn, 1985); p41, 1985]. This may be summarised as 'select, rank, cluster, arrange, link'.

The first step, to select, is to focus on the concept to be mapped. This could be a passage from a text, a background to a laboratory experiment, an engineering science principle (e.g. heat transfer), an engineering component (e.g. bearings) or a statement like 'skills of a professional engineer'.

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The next step in concept mapping is to list key words and phrases to represent and support the basic concept. In the case of bearings, the key words could be 'loads; type - bush/ball/roller; location; tolerance; lubrication; life; cost; etc'. These must then be ranked hierarchically. In the case of the bearings the loads will dictate the type of bearings to be used and, therefore, the type will be of a subordinate rank to the loads.

In most concept maps, and specially in the more complex ones, there will be clusters of concepts that function at the same level of abstraction and interrelate closely. These in fact reflect the judgements about the closeness concepts and will be expressed in the layout of the final map.

Clusters must now be arranged in their hierarchical form and prepared for the links and interrelations to be determined. The layout is now in a two dimensional array. The final step is to link related concepts by lines and complete the map by labeling each line in propositional or prepositional form. As Ault says, of a completed map:

'Once linkages are labeled, the map becomes "a paragraph that reads in any direction (in the words of one enthusiastic student)"........' [p41, 1985].

Each concept-linking word-concept unit forms a proposition that reads like a normal, simple sentence. Concepts not in the original text or brief can be added to the map to increase complexity and comprehensiveness.

Whatever the process it must be noted that any concept map represents the ideas and perceptions of the map constructor. This must be seen as 'a' concept map rather than 'the' concept map of whatever set of concepts it is representing [Moreira, p283, 1979].

In dealing with engineering undergraduates the strategy to introduce concept mapping was to first offer lecturer-generated (ready made) maps as adjuncts to normal course work in Engineering Design. Maps were constructed
and used in the classroom for discussion with students. References to sample maps detailed by Novak [1984] in other discipline were given to demonstrate the wide usage of this technique.

One typical but simple example of a lecturer-generated map of an engineering concept is shown in Figure 13. This was used as an instructional example for the students who were to be involved in the investigation. The map was projected in the classroom as a completed piece of work. The process was outlined in detail to the students and they were encouraged to participate in the development sequence of the map.

The first step shown in this was the concept of gears - the subject for concept mapping. A list was then compiled of related concepts. These were basically the types, materials, combination of different types to give systems, and the history and development of gears and gear drives. Under each of these first level hierarchical concepts, various subordinate concepts were detailed. For example, under materials three different types were listed - metals, polymers and 'others'.

These were further expanded to give many levels of hierarchy to a stage where other engineering components were brought in - e.g. in the transmission of power and torque, the concept of bearings had to be included to decide what type of loads would be generated when a particular type of gear was used and hence the type of bearing that needs to be used.

The concepts were then linked wherever the relationship was clear. The linking lines were labeled to complete the map.

In presenting this sample it became obvious that for any body of subject matter there is always a judgement as to what represents an ideal hierarchy and what and where the interconnections are.
Figure 13: Instructional Concept Map of 'GEARS'
A literature survey on this technique reveals very quickly that the major, if not all, effort has been put at the school level and very little work done at the tertiary level education, particularly in engineering. Novak and Gowin [1984], however, state that it is possible to organise concept maps even for entire educational programmes.

The difficulty in such an exercise in engineering is in the number of concepts and the complex interrelationships between these that make up even the very simply engineered artefacts. Take for example the map shown in Figure 13, of a common engineering component - a gear. On its own it has no basic function. It has to be 'geared' with other gears or systems in order to make it of practical value to the design engineer. Other engineering components enter the field of view and need to be included in order to complete the map.

The links are complex and the example given above is typical of any engineering component. It also became obvious that in dealing with engineering components, mere words were not sufficient - particularly if the concept has to be described comprehensively. During the demonstration of the 'gear' example it was necessary often to resort to schematic (pictorial) representations of components and systems.

Since the training in this instance was primarily aimed at the students becoming reasonably proficient in developing concept maps of a Professional Engineer, it was considered sufficient to limit the maps to purely verbal statements. Students were, in fact, encouraged to use only words and sentences in their construction of concept maps of engineering components - the training part of this exercise.

It is, nevertheless, clear that restricting concept mapping to just words and sentences is an important limitation in the technique and needs
to be studied and researched further - at least in terms of engineering design applications of this procedure.

This introduction was followed by work carried out by students on their own. In the initial exercises only engineering components such as bearings, gears, motors and fasteners were mapped. The subjects were final year students in engineering and were quite familiar with the components and terminology relating to these.

Some examples of the above work are shown in Appendix L. Since these were used as training units comments of the lecturer appear in the samples.

3. Concept Mapping Strategy - Results

3.1 Concept Mapping Training

Prior to involving students in the construction of concept maps, the researcher followed a course of instruction and training in the technique of concept mapping run by the Hong Kong Polytechnic's Educational Technology Unit (ETU) in April 1987. Samples of maps developed are shown in Appendix L (along with maps developed by students). To distinguish these from the others, the researcher's name appears on the top right hand corner of his maps. These were purely for the training of the researcher and were not used further in the exercise.

Concept mapping was introduced to students, at first, through the pre-constructed maps shown in Appendix K. Students were understandably a little apprehensive about the usefulness of the technique to their field of study - mechanical engineering.

It was made clear, at the outset, that they were not being assessed in this exercise and that concept mapping is just another tool that could enhance student's learning efficiency and also a simple method of
externalising their cognitive structure related to any concept, be it engineering or any other. This was accepted cheerfully.

After this introduction, the development of the instructional concept map of gears (Figure 13, p 96) was carried out with 35 students in the class. Students took an active part during this process. Because the component that was being mapped was a familiar one, students did not have problems in actively helping in constructing the map.

However, one drawback to student concept mapping activities that could be difficult is in constructing a map where the learner has only a vague idea of the concept. Such a learner is likely to be overwhelmed and confused by the task if s/he is not properly prepared or trained in such an activity [Stewart, p 175, 1979]. For the first three exercises, therefore, only concepts that were familiar to engineering students were used in the training process.

Since this was a new venture for the students, individual work was considered unsuitable for the first exercise. Too large a group would also pose problems of control and in terms of the groups arriving at a consensus in this kind of subjective activity. Students were, therefore, paired for the first concept mapping work. The pairing was done by the student's themselves.

Each student mapped concepts relating to bearings, motors, fasteners, springs and gears. They were also free to choose any other engineering component or system for the first exercise. Students were also free to make the maps of whatever size convenient to them. There were no restrictions on type of paper, colour, pens, pencils or other materials to be used. The maps could be handwritten, typed or developed on computers. Even video taping was suggested and accepted as a medium.
Students were given the following suggestions for the construction of their concept maps: [adapted from Loncaric, p60, 1986]

1. Select an engineering component - the major concept.
2. Identify in words all major concepts in this.
3. Arrange concepts from general to specific.
4. Circle or highlight concept words.
5. Draw connecting lines between related concepts.

Within the time stipulated 30 maps were submitted by the students (Total number taking part, n=35) involved in this training process. There were, however, no maps submitted that were of other than the suggested engineering components. Most were done on standard white A3 size paper and 75% of the maps were hand written. Two were generated on a computer (PC) and two used type written tab stickers to develop maps.

The maps tended to be very formal (see Appendix L) and extremely well structured in describing types and function of the component. Only two maps had any significant interlinking (see map on Motor, Appendix L) or prepositions linking concepts.

All maps were, however, quite comprehensive in technical content and the listing of characteristics and types (see map of Fastener, for example, in Appendix L).

Maps on the same component constructed by different groups varied in style and, to a lesser extent, in content. All maps were of a high standard in terms of presentation and clarity compared with some found in the course of literature research on the topic of concept mapping (compare with the maps in Appendix K). Literature survey on concept mapping did not reveal
any maps on engineering components or concepts that could be used as a
guideline for this exercise.

It was clear at the end of the training session (three maps) that the
students involved were quite capable of tackling concept mapping of any
topic on which they had reasonable understanding and knowledge. In the case
of engineering components, where the students lacked sufficient depth and
width of technical expertise in a particular area, they were able to obtain
information to complete the maps. All the maps exhibited this approach.

The training, however, was specifically for the generation of maps to
illustrate the student's concepts of a professional engineer. Therefore,
the engineering component maps were discussed in detail with individual
students to highlight the hierarchical nature of the maps and the
interrelationships of major and sub-concepts rather than the technical
contents per se.

This pilot study indicated that the steps suggested for the
construction of concept maps were satisfactory. All students followed these
steps in their construction of maps. The most difficult step for students
appeared to be - from their verbal comments - that of writing the
connecting prepositions or words or sentences.

Students argued strongly that it was unnecessary to write connecting
words where the connection was obvious from the two statements that were
connected. For example, some comments from students went as follows:

'Bearings align, support and reduce friction. So, why
say ...bearings are used to align.....'

'Fasteners can be temporary, permanent or semi-
permanent. The connecting lines take you to the right
types. No need for prep... whatever...'

'In engineering everything is connected to everything
else ..... the map would be confusing.... so only some
are shown... the important ones....'

An inspection of the maps submitted confirms the validity of these statements insofar as interconnections are concerned. To assess the maps in a more formal manner, concept maps scoring measures were studied. Several quantitative measures have been used by researchers in the field. Novak [1984], Bayerbach [1985] and Loncaric [1986] score maps on levels of hierarchy, number of relationships shown, number of cross links and number examples. While they agree on what to assess, each differs on the weighting given to the various facets.

These scoring methods are comparative and grade maps within a class or group. This was considered unnecessary in the investigation in question as the aim was to enable students to become familiar with and free in using concept mapping technique as an 'externalising' tool. There were no pre-and post-test scores comparison.

In discussing the maps with the students, issues addressed were whether the technical content was reasonable; the appropriateness of the hierarchical levels; the interconnections between the major and subordinate concepts as perceived by the student and the usefulness of concept mapping as a learning tool.

3.2 Results

There were 35 participants in the preparation of the maps. Within the time stipulated (1 week), 30 maps were received in response to the question

'What is your concept of a professional engineering design practitioner? Construct a concept map to illustrate your answer.

All but one of the maps placed the professional engineering designer at the centre of the map. The odd one had the designer at the head of the concept map. Various attributes were listed and the more common ones were
extracted by recording the attributes alphabetically and noting the frequency of occurrence among the maps submitted.

The range of attributes varied from the possession of general engineering knowledge to 3-D vision and inquisitiveness. Social qualities were sometimes very clearly stated in terms of specific functions such as design of equipment for the elderly and disabled. 'Character' appeared in most maps, with sub-attributes such as 'confidence', 'hard working', and 'ethics' linked to it.

These are given below in alphabetical order together with the frequency of occurrence quoted where this was less than 50% or 15 (given in parenthesis) in the thirty maps. Where the researcher was unable to infer a precise meaning in words used by students, either a question mark, '?', is placed next to the word or a suitable word/phrase is offered with the '?' following the suggestion.

3D Vision, (1)

Acceptance of new ideas, (1)

Capacity (self efficacy?) (2), Character (12), Community Service (5), Communications Skills, computational Skills, Corporate Planning, Creative Design (also Creativity; Creative Power; Forced Creativity (?); Creative Expression).

Design Appreciation,

Engineering Fundamentals, Engineering Judgement, Energy Conversion (? ) (1), English Language, Experience,

Further Studies (2),

Goals (2),

Hard Working, Health & Safety,

Information Search, Installation and Commissioning, International Trade/Relations, Interpersonal Awareness, IQ.
Labour (Relations?), Learning from mistakes (also Learner), Library(?), Languages (Chinese, French, German, Japanese, Russian), Leadership.

Memory (2), Morality (3), Obedience (2), Obligation (?) (1), Organisational Skills, Optimisation (1), Outdoor Activities,

Peer Group Interaction, Planning Skills, Presentation, Problem Identification, Problem Solving Skills, Professional Ethics, Project Supervision.

Qualification,

Research & Development,

Self-Confidence, Specialist,

Team Work, Technical Skills, Thesis Writing (1),

Work Independently (2).

The list describes more than the average professional engineering designer's role in industry. It does, however, identify the many faceted characteristics that make up the image of an engineering practitioner as perceived by a beginner in the profession. Each map gives some indication of the cognitive structure of the beginner's view of an engineering designer (See Appendix M).

Comparing this with the attributes of an engineer as given in Figure 7 (page 47), the discrepancies may be summarised into three broad areas -

Information Technology - Information Search, Libraries, Thesis Writing, Research & Development, Good Memory, Further Studies, Languages, Presentation, Community Service;

Languages - English, all major Languages, IQ, Trade and relations (international), Presentation, Supervision, Labour (control, relations); and

International Trade and Relations - Projects, Acceptance of new (different) ideas, Environment, Team work, Installation and commissioning, corporate planning.

It could be argued that Languages can be broadly classified as part of
a general communications skill domain. In an area such as Hong Kong (and to a greater extent mainland China) languages other than the local dialect of Chinese is a skill that needs to be acquired. Therefore, this area is classified as a separate skills area to be developed for the engineer in general. This may be a global requirement in engineering education rather than a local peculiarity, if we consider Batley's comments [Batley, p44, 1987] in the context of management skills to develop professional status.

The growth in Information Technology affects the professional engineer just as much as any other professional. The Alvey programme in UK is an indication of the recognition given to information technology and its strategic significance in the coming decades. Engineers need to be made aware of this major area of development.

International trade and relations affect the engineer employed by multi-national organisations. Project work, acceptance of new and different ideas, involvement in corporate planning and installation and commissioning of plant and equipment are common activities of engineers in Hong Kong. Attributes needed for these activities involve more of management and interpersonal skills than technical ones.

All other items in the list can be absorbed under the umbrella of various individual items given in Harrisburger's [1976] list of attributes for a professional engineer (Figure 7, p47).

For example, similarity is seen in:

<table>
<thead>
<tr>
<th>Student Quoted Attribute</th>
<th>Harrisburger's Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptance of new ideas</td>
<td>Engineering Judgement</td>
</tr>
<tr>
<td>Character</td>
<td>Integrity (Autonomy)</td>
</tr>
<tr>
<td>hard working</td>
<td>Integrity</td>
</tr>
</tbody>
</table>

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Obligation  Professional Ethics
Morality  Professional Ethics
Optimisation  Problem Solving/Creative Expression
Problem Identification
Peer Group Interaction  Self Confidence Building (Autonomy)
Working Independently  Integrity/Autonomy
Experience  Organisation/Leadership
Specialist  Professional Status/Identity

The concept mapping exercise also showed that the beginner in the profession, the student, views the professional in a broader sense and sees the role as comprehensive and all-inclusive.

The conclusion from this exercise is that the student's view of the professional engineer tallies with the list (Figure 7, p47) of skills that Harrisburger has produced with the three additional areas of Information Technology, Languages and International Trade and Relations.

A further unexpected result of this exercise is that the research tool, concept mapping technique, has been embraced as a learning tool by some students. This is only an assertion based on private communications with students and needs to be verified. The indications from the maps submitted by the students are, however, that such an adoption will be beneficial in the understanding of concepts in engineering. This needs to be researched more comprehensively and is beyond the scope of the current work.
CHAPTER 6

Interlinking Skills Model

Introduction

In the last chapter, data from undergraduates and practitioners was collected and analysed to identify the utility priorities of various academic subjects and professional skills. The results gave both technical competency requirements and the interpersonal skills (in terms of academic units) needed for an effective career. Although the technical competence and the interpersonal skills can be isolated for analytical purposes, they must be understood with reference to the dynamic unified whole - especially in any curriculum model for the education of the professional engineer.

The goal of the model that is to be formed in this chapter is, therefore, to direct engineering design curriculum development. In presenting this model each concept will be defined and supported by theoretical underpinnings. Wherever possible and is necessary, references to other disciplines and professions will be made to justify generalisation and assumptions.

Skills Model

1. Theoretical Underpinnings and Educational Strategy for Skills

1.1 Technical Competency

The review of engineering education (Chapter 2) and the related literature survey (Chapter 3) revealed various technical and professional skills for the effective practice of a professional engineering designer. The technical competency included core knowledge of academic discipline and other cognitive skills as shown below:

- Acquisition and Application of Discipline knowledge;
  (Engineering Fundamentals)
- Problem Solving skills;
Creative Expression/Creativity;
Engineering Judgement;
Critical Thinking;

Engineering fundamentals are basically the core academic units in any undergraduate course. They provide the technical knowledge and the theoretical base for professional practice. In the effective application of this acquired knowledge, i.e. in engineering design, the other cognitive skills listed above are desirable.

a) Problem Solving

Overview

'A problem is a stimulus situation for which an organism does not have a ready response' [Davis, p12, 1973]. In surveying the psychological theories that explain the actual mental process of solving problems, Brightman [1980] divides problems into two categories:

a) ill structured operating problems and
b) ill structured strategic problems.

In engineering design the problems of the designer are generally ill-structured operating type - novel, elusive, and not always clearly specified. They cannot be solved by cut-and-dried methods and need custom-tailored solutions. Only the theories relating to this are discussed below.

Four models are described by Brightman [1980] for the solution of the operating problems - behaviourist; cognitive; information processing; and experiential models. The first three are derived from the psychology of problem solving while the fourth is based on actual problem solving in business situations.

The behaviourist model reduces problem solving to simple principles of stimulus (problem)/ response (solution / reward (behaviour). While this may be satisfactory for animal behaviour and simple repetitive tasks for man it
does have serious shortcomings for more complex problems that engineers are likely to be faced with. This model eliminates conscious and deliberate activity and problem solving is reduced to stimulus-response mechanics.

The cognitive model attempts to explain problem solving as a conscious process. It takes into consideration the positive effects of hints and cues and the negative effects of habits and conformity in problem solving. The drawback in this model is that most of the experimental work in this has been on carefully defined problem situations. Real world problems are not so well defined and neatly structured [Brightman, p11, 1980].

Recent problem solving models based on information processing systems attempt to reduce complex situations to a set of elementary processes that produce, imitate and duplicate human thinking [Newell & Simon, 1972]. This approach also addresses only well defined and structured logic problems.

The experiential model is based on observation of successful problem solvers at work. Three stages were proposed by Dewey [1933] - diagnosis, analysis and solution. Emphasis is placed on the experience and knowledge of the problem solver.

In engineering design, problem solving refers to a multi-stage process of a specifications-to-a-product analysis aimed at developing an artefact [Gregory, p12, 1966]. It is a systematic process through which an engineer makes decisions. This may involve the application of general heuristic processes (means-to-an-end analysis, trial and error, and generate and test) and to view a problem as comprising a number of smaller 'chunks' or 'patterns' of problems.

Solving engineering problems is generally a knowledge-rich task - this is true for both the novice's and the expert's tasks. Investigations [Chase & Simon, 1973] have shown that:
relations between the structure of a knowledge base and problem solving processes are mediated through the quality of representation of the problem. ... is constructed by the solver on the basis of domain-related knowledge and the organisation of this knowledge. ... determines the quality, competencies, and coherence of the internal representation, which in turn determines the efficiency of further thinking. The representation of a problem consists essentially of the solver's interpretation or understanding of it, and greatly determines how easy it is to solve.' [Gagne, p68, 1987]

It is, therefore, self-evident that problem solving minimally requires that we first recognise the nature of the problem and its existence and then proceed to solve it. The various stages in this process of arriving at the solution is only an elaboration of this truism [Davis, p15, 1973]. Many authors have accepted the four stages for problem solving (and indeed creativity - see later part of this chapter) suggested by Wallas [1926]:

**preparation, incubation, illumination and verification.**

These are terms that are used widely by researchers and authors in the field. Many have maintained the original terminology while some have modified or amplified them.

These stages are similar to the stages proposed by almost every author on the basic engineering design process - needs identification, generation of ideas and synthesis, and analysis leading finally to the manufacture of the product.

The initial stage in problem solving requires a priori judgement regarding problems worth working on. Salient cues and clues from the environment must be acquired by the problem solver to make decisions. Accuracy of this a priori engineering judgement is essential in coping with or adapting to situations of uncertainty. In an individual this attribute
is partly developed and shaped by his past and current interactions with his environment.

There is, however, a tremendous variability in human beings and it is not clear whether these differences are due to heredity or learning or both. The skills involved in the problem solving activity can still be increased through the deliberate teaching of appropriate attitudes for producing ideas [Davis, p18, 1973].

As outlined above, studies from different psychological perspectives come to differing conclusions on problem solving theories. The behavioural psychologists present problem solving from a trial-and-error and a simulation-response (S-R) activity base. The cognitive-gestalt theory pundits analyse the internal processes. Psychometrics is concerned with intellectual traits and information processing involves the simulation of human thought (cognitive) process using the power and the speed of the ubiquitous computers (Artificial Intelligence).

In the literature on the education of engineering designers there is no clear guidelines for the development of problem solving skills. Many models are proposed for the tackling of individual projects [Fletcher, p190, 1986; Tebay, p89, 1984]. But none go further to identify ‘how?’.

Engineering is not the only profession to suffer from this. The medical profession also has a similar dilemma. Looking at models for medical problem solving, Long [1983] states:

...research efforts yield inconsistent findings as problem solving abilities varied according to situation and appears to depend upon the individual’s acquired skills and his or her mastery of the problem to be solved (Vu, 1980).’ [Long, p99]

Theoretical explanations of problem solving process offer many views of this complex concept and highlight the individuality of human beings. In
practice engineering problems are seldom solved by individuals. Most designs are a group activity and this brings in aspects of group problem solving processes.

It is clear that while the theoretical explanations of problem solving differ, problem solving skills in the engineering designer need to be developed for effective professional practice. Thus, both the content and process of problem solving should constitute a major emphasis in the education of the designer.

Educators in engineering have no option but to consider all the theories offered by the educational psychologists at this stage. Only the consideration and application of these in the development of the engineering curriculum will enable the outright discarding of any theory justifiable.

**Educational Strategy for Problem Solving Skills**

The identification of educational strategies to develop problem solving skills is also complex. Many techniques for this are presented in the literature [Rickards, 1975; Rawlinson, 1981; Brightman, 1980]. SEED [p27, 1985] states that in ideas generation, the following techniques are considered suitable:

>'Attitudes, approaches and simple techniques such as analogy, inversions, brainstorming, etc...'

- Common techniques in problem solving employed by disciplines such as management, medicine, product design, nursing, food products are:

  - Analogy and Metaphor Procedures
  - Attribute Listing
  - Bionics
  - Boundary Examination
  - Brainstorming
  - Goal Orientation
  - Idea Checklist
Morphological Synthesis
Nonlogical Stimuli
Recorded Round Robin
Relevance system
Research Planning Diagrams
Reversals
Successive Abstraction
Synectics
Trigger Sessions
Weighting Systems Wishful Thinking
Wildest Idea

Some of these are individual re-structuring techniques while others are re-definitional. Some like brainstorming are group techniques. These are well established aids for problem solving and are covered abundantly in the literature [Rickards, 1975; Brightman, 1980; Davis, 1973]. Each has its value in general but need to be assessed seriously in the engineering design context.

This is not to say that these methods are of no value in the education of the engineering designer. On the contrary, it is important that the beginner is familiar with these tools at an early stage of his career. These enable the novice to explore his own knowledge and relate core academic units into a cohesive whole. Some of his inhibitions may be removed during well organised and conducted group activities such as brainstorming and trigger sessions.

Many practicing engineers suffer from this inhibition. Heywood, commenting on his pilot survey of job analysis of practicing engineers [1981] states that:

'... past experience sometimes inhibited problem solving when the engineers were faced with an entirely new problem.' [p516]

The moral here for the beginner, however, is that he must 'learn how to learn' while an undergraduate. Heywood stresses this point and relates problem solving to innovation and the process of engineering design.
Brunel University has mounted a 'problem-solving course' [O'Connor, 1984] in its enhanced Special Engineering Programme (SEP) to get the student to:

'... appreciate fully the essence of engineering activity as problem solving, which, as a function of thinking, requires a degree of self awareness on the part of the student, particularly in relation to the modes of thought he brings to bear in dealing with the problem at hand, and how he organises and applies his ideas.' [p698]

Because of its generality, the course at Brunel does not depend on any particular subject matter, although many examples from a variety of fields are used as illustrations of strategy, identification of the problem, stating this clearly, assumptions, generation and organisation of ideas. While this is a step in the right direction it could be argued that merely having a course in problem solving will not develop problem solving skills. Such skills, even if displayed during the course, may not be generic. Problem solving has many facets and it is the individual facets that need to be addressed in order to develop the 'whole' skill.

In undergraduate courses, a student is expected to develop competence in all areas of the discipline. Career details of practicing engineers reveal (Chapter 4, p. 77 & 78) that such a wide expertise is not required in industry. It follows then, that it is more beneficial to identify the beginner characteristics more accurately and, based on this information, offer him the necessary choices depending on his ability and commitment to problem solving and design. Such an approach may be applicable only after the first year of a course and gives both the customer and the vendor to set up a mutually beneficial deal.

However, taking Wallas' list of four stages of solving problems (see
this Chapter, p110), a course in engineering design should set out to develop proficiency in each stage in a student, for, without skills in one he cannot cope satisfactorily with the next stage.

Also, because individuals differ so widely, their level of proficiency cannot be expected to be uniform in all stages of the design process. The educational strategy, therefore, must be to enable each student to identify his strengths and weaknesses and to capitalise on his preferences. Design courses must incorporate necessary flexibility to allow for individuals to enhance and attain their true potential.

Such an approach also develops and enhances the accuracy of judgement and builds up confidence in the beginner.

**Summary**

The process of problem solving involves mental acts of perception, cognition and evaluation. It is a multi-stage process of bridging the gap between what is there and what is desired. In the education of engineers, training in problem solving is still in its infant stage. There are rare instances of actual courses in problem solving for engineers, one of them is at Brunel University [O'Connor, 1984]. The medical profession appears to be tackling this issue in a more urgent fashion [Brightman, p3, 1980]. Primary and secondary education are also well served by problem solving programmes [Davis, 1973].

In the education of engineering designers it may well be beneficial to remember that in problem solving there are more wrong solutions than correct ones and when a student solves a problem he should be reasonably sure that his solution will, in fact, solve the problem. Wallas' [1926] four stages of the problem solving process need to be stressed in undergraduate courses in design.
Related educational strategies studied yield inconsistent findings. What does emerge from these studies is that the student needs a state-of-the-art core knowledge base and competence from which he can exercise his powers of synthesis to conceptualise solutions to problems. Determining the feasibilities of alternative solutions to a problem will demonstrate to the students the cognitive processes they used in solving the problem. Such self-knowledge and cognition discloses these routes as activities necessary for problem solving. An important starting point is to discover his likes and dislikes, his tastes, his own line [Polya, p206, 1973].

Artificial Intelligence, expert systems, knowledge based systems, computer assisted learning and simulation, information processing systems and some of the techniques quoted earlier (p 112/113) appear to be the most promising methodologies currently offered for training the professional to be competent in problem solving.

b) Critical Thinking

Overview

Critical thinking or reflective thinking as termed by John Dewey [p15, 1933] requires more skills than are used in straightforward problem solving. It is the judicious application of core knowledge and experience to problems and solutions.

The process involves five steps, when considered as specified by Dressel and Mayhew [1954] starting with the definition of the problem. The next step is to collect the relevant information on the problem. The stated and unstated assumptions need to be identified and suitable hypothesis is then formulated. The final step is to draw conclusions and judge the validity of the inferences.
In addressing critical thinking as an educational ideal, Siegel [1980] defines this quality in a person as:

'... the ability and willingness to be objective, impartial and non-arbitrary, based on evidence.'

A further expansion of the process is suggested by Ennis [1979]. Critical thinkers think rationally and have all of the following proficiencies. They:

- are observant;
- can generalise;
- can conceive and state assumptions;
- are able to reason and are logical;
- can evaluate authoritative-sounding statements and situations, deductive and inductive reasoning, and definitions;
- detect standard problems and offer appropriate solutions.

The literature also indicates that rational thinkers are well informed; positive; assertive persons; and do not shy away from value questions [Baker, 1981]. The process requires the ability to:

1. recognise a problem and state it clearly;
2. collect relevant data on problem;
3. recognise unstated assumptions and values;
4. comprehend and use language with accuracy, clarity and discrimination;
5. appraise evidence and evaluate arguments;
6. recognise the existence (or non-existence) of logical relationship between propositions;
7. arrive at conclusions and generalisations;
8. test these; and
9. render accurate judgements about specific things and
It is evident that reasoning and logic are prime requisites for critical thinking. Reasoning is a process of thought which allows a person to apply something known or believed to be true repeatedly in order to arrive at other supposed truths in search of evidence. Logic, which is the study of reasoning, dictates and determines the routes of inquiry. Such processes of thought and logical routes are established within the cognitive structure of an individual through their experiences.

Psychologists have long been debating the relationship between logic and the process of thinking. While there are many schools of thought - psychologism, that places logic as a derivation of psychology; logicism, that reduces psychology to logic; and a school that separates psychology and logic completely - the important aspects of critical thinking for engineering educators are the logical operations. The significant ones are problem identification; interpreting and evaluating alternative solutions; to take a decision when the evidence and reasons are sufficient; and the exercise of informed engineering judgement in all these stages.

Research has shown that only about half the number of beginners arriving at the doors of tertiary institutions (in the USA) are capable of formal or structured thinking [Elkind, 1962]. This skill obviously needs to be developed at the college level.

Irrespective of the discipline considered at college level, critical thinking in general involves making persistent efforts to examine any belief, product, system or solution in the light of evidence that supports it and the further conclusions to which it tends [Dewey, 1933].

This is another way of stating, the general process of engineering design described by most authors on the subject [Gregory, p12, 1966;
Therefore, while there is a lack of data and information on research into critical thinking abilities of engineers, we can support the view that there is no universally accepted definition of critical thinking and also assume that the significant aspects of this ability are the same for all professions.

**Educational Strategy**

The general aim of developing critical thinking abilities in students is to prepare him to become competent and self-sufficient in adult life. A specific aim of engineering schools must be the development of an attitude that considers any technical problem in a thoughtful way and the use of logic and reason in the synthesis and analysis of problems.

As stated earlier, in engineering design, critical thinking is in effect the description of the necessary stages of the activity. One technique that has been applied in the engineering industry for many years now is Value Analysis.

Value Analysis or value engineering has been considered a form of critical thinking process of evaluating engineering design solutions. This is carried out in stages and has defined steps that are followed. It uses a questioning approach to evaluate the function, its need, and costs of a design. Davis & Scott [1971] explain this process in detail describing the Lockheed-Georgia Value Engineering Programme.

To facilitate this some or all of the down-to-earth modes suggested by Osborn [1953] may be employed. One of his famous pragmatic approaches is the *Brainstorming* principle. This involves the designer to think critically at one time and then creatively at another. This is detailed further in the
next section on creativity for which this technique is also suitable.

**Summary**

The theoretical and empirical literature research gave no single accepted definition of critical thinking. The process, however, involves logic and reasoning. It is a generic skill and can be transferred across subject areas.

There was no empirical evidence to support an integrated engineering curriculum design as facilitating critical thinking. Some of the more accepted and validated methods which facilitated critical thinking in general are (i) formal and structured practice of logical analysis and reasoning of subject matter connected with problems; (ii) discussion of critical thinking as a classroom exercise; (iii) use of techniques such as brainstorming to generate peer group interactions; (iv) tactful faculty encouragement; and (v) use of computer programmes requiring inductive and deductive reasoning skills.

c) **Creativity**

**Overview**

The concept of creativity has as many definitions as there are authors on the subject. The psychology of creativity tends to be theoretical rather than pragmatic. Often innovation is confused with creativity. A review of the literature produces many definitions.

'Creativity, a prerogative of man, can be seen as the humble human counterpart of God's creation.' [Arieti, p4, 1976] (original italics)

'I find it futile to deal with creativity at a single level of explanation, be it the genetic, the psychological, or the historical. I find it equally unprofitable to isolate a single element as the key to creativity ... requires a combination of disciplines and perspectives.' [Gardner, 1983]
'Creativity is the ability to see (or be aware) and to respond' [Fromm, p44, 1959]

'... It is at times a sudden intuition, or a clear insight, or a feeling - something between a "hunch" and a "solution" and at other times the result of sustained effort' [Wallas, 1926]

'As a part of both pop culture and psychological jargon, "Creativity" is used to cover everything from measures on certain psychological tests to forming a good relationship with one's spouse' [Hutchings, p43, 1987]

'Creative *attitudes* include a conscious intent, sometimes even eagerness, to search for imaginative ideas and viewpoints, to escape from habit, tradition and conformity pressure, to seek novel products and problem solutions.' [Davis, p9, 1973] (original italics)

These definitions differ in their fundamental theme - in them creativity is either a process or a product. From an engineering education point of view, the dualistic stance of creativity must be unified and viewed as a whole. The act of creation is as important as the product of that act. The interpretations of the creative process as postulated by Wallas, Osborn, Guilford and Wertheimer all seem acceptable as a starting point in understanding this complex subject.


The attitudes include eagerness to search for imaginative ideas, to escape from habit and tradition, and seek new solutions to problems. These are quite voluntary determined by the individual's attitude towards new ideas, change and innovation. The abilities refer to mental activities of abstracting, combining, associating, imagining, filling in missing
information, perceiving novel relationships, or taking 'intuitive leaps'. The training of such processes are difficult. They can, however, be nurtured through exercise and reinforcement.

The most important of these attitudes is a strong, positive orientation towards innovation and new ideas. Rogers [1959] believes that certain conditions within the individual are associated with creativity. These include an openness to experience, an internal locus of evaluation, and the ability to toy with elements and concepts. The integration of these elements is the mark of a creative person.

Wallas' [1926] stages of creativity are probably the most accepted and imitated by researchers in the field - with minor variations in the definitions of the stages. These are: preparation, the individual seeks understanding of the problem; incubation, the unconscious makes unexpected connections that constitute genuine discovery; illumination, caused by the connections and where solution to the problem is unfolded and grasped; and finally, verification, where the conscious notes the values and establishes the implications of the solution to the problem.

Creativity and its interrelationship with intelligence is a major issue among researchers in the field. Guilford [1966,1967] and Torrance [1962] studied this relationship and Torrance concluded that a necessary threshold of intelligence for creative thinking is an IQ score of approximately 120. Davis [1973] and Rawlinson [1981] content, however, that 'anybody who can read these words is more than capable of stretching his mind in a completely deliberate manner. He can voluntarily think of never-experienced things...' [Davis, p133]

'Without exception, everybody has creative ability' [Rawlinson, pl.]
Many other investigators have studied the creativity-intelligence relationship. Bolton [1972] concludes that:

1. The correlation between creativity and intelligence, as defined by performance on tests of divergent thinking, decreases with increasing intelligence and decreasing test atmosphere.

2. Different tests of divergent thinking and different measures (e.g. fluency, flexibility, and originality) within the same test correlate highly among themselves to form a unitary dimension, although verbal and non-verbal components may be distinguished.

3. The relationship between divergent and non-divergent tests awaits further clarification from studies which control for test atmosphere and range of intelligence. [p202-203]

Creativity has been researched extensively and there is a plethora of publications on the subject that is both confusing and conflicting. For the education of engineers, however, some generalisations that can be considered are:

- creativity is a process that can produce a product;
- fluency, flexibility and originality are characteristics of creative individuals;
- individual should have a strong, positive orientation towards new and innovative ideas;
- creativity needs faculty support, it does not appear automatically if students hang about the campus for three years or so.

The literature also shows that there is a definitive and, in most cases, a positive relationship between creative ability and professional performance [Long, p120, 1983]. It can therefore be concluded that engineering education should address the teaching of creativity seriously at the undergraduate level.

**Educational Strategy**

The levels of achievement of Albert Einstein in his school mathematics
is a legend. The disturbing uncertainty of this story is not whether it is true or apocryphal; it could be happening in every lecture room today. While the probability of encountering another Einstein in our engineering classes may be infinitesimal and very remote, the question that should be raised by the legend (one we should be asking) is 'What are we doing to encourage (dare I say develop? [Estrin, p259, 1963], original italics) creativity in the students?'

Educators in engineering today are addressing this question. Current movements in engineering education circles make creativity a particularly significant concern. Engineering courses are tending to be more and more design biased and creativity is a central issue in the teaching of design. Engineering educators must now grow out of the romantic illusion that creativity is beyond analysis and that it cannot be taught.

Various techniques exist for the development of creative thinking. In a broad sense, affecting racial groups and nationalities, nine socio-cultural creativogenic factors are suggested by Arieti as necessary for the development of creative thought:

1. Availability of cultural means;
2. Openness to cultural stimuli;
3. Stress on becoming and not just on being;
4. Free access to cultural media for all citizens without discrimination
5. Freedom or even retention of moderate discrimination, after severe oppression or absolute exclusion;
6. Exposure to different and even contrasting cultural stimuli;
7. Tolerance for divergent views;
8. Interaction of significant persons; and
9. Promotion of incentives and awards. [p324]
The above are a national level statements. The first one is the most important factor and absolutely necessary, as argued by Arieti. The absence of the others can be overcome by a creative person.

At an undergraduate level and at a college level some questions that may be addressed by faculty to help in facilitating creativity are suggested by Hilgard [1959].

1. Does the student initiate inquiry on his own or only inquire along lines set by others?

2. Are there opportunities to exhibit and take responsibility for successive evidence of creativity even though the created items are not "distinguished"? That is, does the student learn to take satisfaction in small evidences of creativity?

3. Are there opportunities for the student's original work to be judged according to individual progress rather than according to group norms?

4. Is there time in the programme for a substantial investment of time in idiosynchratic specialisation?

5. Is there evidence that the progressive changes during the academic year are towards greater diversity of talent rather than greater conformity? [p180]

Sullivan [1963] commenting on risks that students take in the process of being creative says that

'the creative act must be uninhibited and marked by supreme confidence; there can be no fear of failure - nothing inhibits so fiercely, or shrinks a vision so drastically, or pulls a dream to earth so swiftly, as the fear of failure'.

In developing creativity and creative thinking, Osborn [1963] suggests that quality is a function of quantity i.e. greater the number of ideas generated by an individual, greater the number of high quality ideas contained in the total number. This requires fluency of ideas and a common strategy for this is a forced activity - the brainstorming technique. The
technique overcomes the barriers to creative thinking by following rigid principle of deferred judgement, the self-evident notion that criticism and at least harsh evaluation will interfere with flexible idea production.

The brainstorming process is simple and does not need training. Students can participate after a few minutes of clarification of the fundamental rules. The four ground rules are:

- Criticism is ruled out.
- Freewheeling is welcomed.
- Quantity is wanted and
- Combinations and improvements are sought.

For brainstorming sessions group size should be ten to twelve members. There should be a leader; an associate leader; five regular members; and five guests. To increase source and variety of ideas the group should be heterogeneous in training, experience, and sex. Equal rank among members is desirable. Students should be informed of the problem to be discussed at least 48 hours in advance so that they come to the session reasonably well prepared with ideas. Session duration of 30-45 minutes is considered suitable for most problems. Leaders could take hints from Osborn's [1963] "seventy three idea spurring questions" to keep the session in progress and handle any 'uncomfortable silent periods' [Davis, p96, 1973].

de Bono [1986] believes that lateral thinking enhances the probability of insight and creativity. He suggests brainstorming sessions [p146] are of value as a formal setting which encourages creativity through lateral thinking. This is stated in the context of a cross-stimulus group activity and as a special setting in which to practice lateral thinking in a formal way to start with. Later on there is less need for such formality and the individual can apply his lateral thinking ability to any design problems on
his own.

Cattell's research and studies [1970] relate creativity to personality. He states that creative personality traits remain much the same in science, literature and the arts [ibid., p. 239]. Creativity does have this wide range of expressions and the relationship between personality and creativity in an engineer needs to be researched further before even assertions are put forward in this. On a general note, Cattell points out that the outstanding characteristics of (time study) engineers besides intelligence, is sophistication [ibid., p. 220]. This in the context of hard-headed realism, is backed up by a strong willingness to try out new ideas. The message here for design educators is to positively encourage students to try out novel solutions to problems - in trying to develop creativity.

Summary

Without exception all individuals possess creative abilities [Rawlinson, p1, 1981]. The three main components are attitudes, abilities and techniques. The mental activities involve abstracting, combining, associating, imagining, filling in missing information, seeking and perceiving novel solutions to problems and taking 'intuitive leaps'. These activities can be nurtured and reinforced through exercises. Effective methods for stimulating creative growth in engineering design appear to be ones that develop lateral thinking and fluency in generating ideas. It is also clear that to motivate students to be more creative, a caring and supportive faculty is an essential element.

Engineering design curriculum designed with emphasis on problem solving and positive orientation towards new and innovative ideas will also
promote creative ability in the student. Open ended problem solving exercises are suggested in the literature, particularly by practicing engineers [Wilde, 1983].

Of course, in the search for the solution to a problem there is the philosophical paradox of looking for something which is unknown to the student. Plato (as quoted by Bolton, [1976], p181) first pointed out the contradiction (in the *Meno*) that seems to be inherent in talking about discovery. He says:

'To search for the solution of a problem is absurd, for either you know what you are looking for, and then there is no problem, or you do not know what you are looking for, and then you cannot expect to find anything... if by chance you should stumble upon it, how will you know that it is, indeed, the thing, since you are in ignorance of it?' [Bolton, p181, 1976]

The paradox implies that creative thinking is meaningless and impossible. In engineering design, however, solutions are the fruits of mental labour in assembling elements of engineering components and applying explicit scientific principles in analysing their individual and assembled functions.

There is no evidence to suggest that innovative engineers have tacit foreknowledge of as yet undiscovered artefacts. The emphasis in the education of engineers should, therefore, be on the awareness of how problems were solved by engineers of the past and subsequent improvements that have been made with advances and progress in scientific knowledge and technology. A study of the history and philosophy of science and technology could be a sound starting point in creating this awareness.

1.2 *Interpersonal Skills*

It is not the purpose of this research to study in detail the philosophical aspects of interpersonal skills (such as ethics, integrity,
autonomy, self efficacy and self-confidence) related to the education of the engineering designer. Each of these social skills is a discipline in itself commanding libraries of treatises and other learned works.

It is sufficient to state that for effective professional practice, there is necessarily a relationship between the social identity of an engineer and his technical competence. Much of this relates to the socialisation process of an individual interacting with his environment as a professional.

Since professional schools have become almost the exclusive gateway to a profession [Houle, p88, 1987], those concerned with professional education must carefully consider how the technical competence and the social identity can be interlinked during the educational process. This inevitably involves institutional policies and curriculum planning based on value judgements of the society in which the institution operates.

Some of the social skills are discussed in brief only insofar, as they make the model of the necessary skills for the engineering designer visibly complete and allow propositions to be formulated in terms of their effect on the technical competency of the designer.

The common social skills for effective professional practice referred to in the literature on the education of professionals are ethics, integrity, autonomy, leadership, self-confidence, and self efficacy. These are discussed in brief to provide a base for identifying directions in curriculum development.

a) Integrity and Ethics

Ethics refers to the science of morals in human conduct, according to the meaning given in the Oxford Dictionary of Current English [1987]. The
word is derived from the Greek word 'ethos' meaning character. Integrity is derived from the Latin word 'integer' meaning whole or untouched. In the above dictionary, integrity is equated with honesty, wholeness and soundness.

The moral dimension of human life seems to presuppose the following three points:

1. There is a real and important difference between actions which are right and actions which are wrong.

2. In many cases, we have the capacity to know, or at least to have justified beliefs about, which actions are right and which actions are wrong. However, there may well be cases in which, at least for the moment, we can only guess.

3. This knowledge (or justified belief) of what is wrong can have an impact on our behaviour. Specifically, we are sometimes led to do an action solely because we come to know (or justified in believing) that it is the right thing to do. Similarly, we are led not to do an action solely because we come to know (or to be justified in believing) that it would be the wrong thing to do. [Brody, p4-5, 1983]

Not all ethicists have been willing to accept these presuppositions. Some, called the ethical nihilists, deny that there is any difference between right and wrong. There are also ethical subjectivists who view right and wrong from the personal approval or disapproval aspect. There are also skeptics who deny the possibility of knowing which actions are right and which are wrong. Some believe that factors in our background, independent of our moral knowledge, lead us to behave the way we do, and that our moral knowledge have no casual significance.

A general aim of education (by extension, of professional education also) is the intellectual and moral growth of the individual. Ethical issues and dilemmas are present in all the professions. In medicine, for example, morality has been a central issue since the times of Hippocrates.
All Professions have some code of ethics to insure the protection of human rights and individual autonomy (see Chapter 3, p. 34 for Engineer's Code).

The codes provide a guideline for the professional to exercise his judgement in situations that are complex and involve health and safety of others. This responsibility, to the 'client', varies with professions. In professions such as medicine and law, the practitioner and the client are generally on a one-to-one relationship and often it is a long term commitment. In comparison, engineering is by nature a team activity and decisions within the engineering dimension reflect the interaction of many such teams [Finniston, p136, 1980].

In the legal profession, it has been shown that ethical responses increase as students progress through the course and that practicing lawyers had lower ethical standards than students [Thielens, 1969]. Such studies for engineers have not been reported in the literature.

It is, however, evident that integrity and moral judgement or ethics are necessary ingredients for effective professional practice. Most professional schools have now embarked on the teaching of values, morals and ethics to foster character building over and above the development of intellect. In engineering education, some schools have introduced liberal education and humanities as appendages to courses rather than an all-permeating philosophy that sets out to prepare a student to deal adequately with critical human choices, especially those with moral consequences.

In the case of the design engineer, the question is whether levels of moral reasoning have any correlation to creative thinking and problem solving abilities. Some doubts have been expressed about the ability to teach democratic principles (hence foster understanding of moral judgement
Tan-Williams [1978] in reporting a study on pre-service Canadian teachers.

The task of developing courses that provide a comprehensive education in moral judgement and instill professional integrity in an undergraduate is an awesome one. An important stage in this process is to expose every student to both ethical theory and applied ethics so that he is left with an awareness of his moral responsibilities and the human consequences of any decisions he may take as a professional engineer.

b) Leadership/Autonomy

Autonomy of an individual implies freedom of self determination and authority. In professional life an individual is invariably required to make a decision or a choice and is responsible for the resulting consequences of his actions. This ability to assume responsibility for his judgement is the mark of a professional.

Professions such as medicine and law have achieved significant levels of autonomy for their members. This organised autonomy provides for the evaluation of a member only by others in the same field. This autonomy is the acknowledgment of the worth and trustworthiness of the profession by society at large. This is a collective award to the profession.

Such a recognition has not been conferred on the engineering profession in most nations. If this is the central attribute of a profession [Freidson, 1973], i.e. the control and self-monitoring of work carried out by members of the engineering profession by others in it, then the relationship with the client must be on a one-to-one basis. This will ensure that the expertise and work of the engineer is generally beyond a layman's understanding and evaluation. Engineers, however, work in teams and are normally employed by organisations.
It is, then, the autonomy related to the individual that should be addressed in the education of the engineer. As an employed professional, the engineer's autonomy is restricted and could be an inhibiting factor when application of creative and critical thinking are called for. The dilemma is often the choice between the employer's entrepreneurial needs and the safety and effectiveness of the design solution alternatives. Integrity and ethics are involved and individual autonomy does not give a professional total freedom.

Effective leadership requires an understanding of two basic characteristics of human nature: the rational tendency and the emotional need. In a review of the leadership literature, Stogdill [1981] suggested various perspectives and defined leadership to cover a wide range of meanings from a function of group process to the initiation of structure. In terms of activities and skills, Mann [1965] offers four main types:

- Technical skills, the ability to use pertinent knowledge, methods, techniques, and equipment for the performance of specific tasks and activities.

- Interpersonal skills or human relations, the ability to use pertinent knowledge and methods for working with people.

- Administrative skills, ability to think and act in terms of the organisation.

- Institutional skills, representing the entire (group) organisation in interaction with the other organisations and groups and government agencies that form the environment of the organisation. [Lassey, p15-16, 1983]

Leadership, in the context of engineers, refers to technological and managerial leadership [Finniston, p54, 1980]. Engineers perform their tasks within a group framework and team work is an important aspect of their attributes. In such a situation a team leader is necessary to ensure the task is performed to schedule and to specifications.
While all four skills listed above are necessary in a professional engineer, the traditional conceptions of organisational functioning do not apply in the case of engineering design projects. The role of the leader and his interaction with the design group is more of a collaborative nature than hierarchical.

People, even engineers, must be led. People perform best under leaders who are creative, imaginative and aggressive - under leaders who lead [Gilb, 1966]. In engineering design the stimulation of creativity and critical thinking in solving problems can be enhanced by tactful and imaginative leadership. Various techniques suggested for promoting creative activities (e.g. brainstorming; synectics; goal orientation) require this leadership in a designer.

The development of autonomy and leadership in an engineering student can be enhanced by providing opportunities for independent decision making and actions; joint planning and execution of design appraisals; opportunity to enact the role of a professional designer; and an apprenticeship-master relationship with faculty.

c) Self-Efficacy

Self-efficacy is concerned with judgements about how well one can organise and execute courses of action required to deal with prospective situations that contain many ambiguous, unpredictable, and often stressful elements [Bandura, p200, 1981]. In a constantly developing technological environment, the engineer has to adapt and change his strategies to effectively manage the interactions.

The origin of the concept of self-efficacy can be traced to social learning theories. The research literature on the application of self-
efficacy theories - direct experiences of personal mastery; vicarious experiences by observation and proximal goal setting - relate to getting rid of phobias or other clinical interventions [Bandura, 1977]: None of these is empirically validated in terms of a professional engineer and his ability to cope in situations of uncertainty.

The literature does, however, show that the increasing complexity of man's existence, particularly the mental capacity required to cope with this, demands a more complex sensory and motor organisation, and even more fundamentally for a better organised cerebral mechanism [Lukasiewicz, p 373, 1972]. Enhancement of the perception of self-efficacy will go towards this aim.

2. List of Skills from Survey and Student Concept Maps

2.1 Skills from Survey

The survey (detailed in Chapter 4) concluded that the participants' nominated subjects and priorities were closely related to those used on a general basis. They were also related to the subject areas that they used frequently in the immediate past - the past five working days. The utility of these academic units is in the inherent skills that each area implies.

These skills are identified with reference to existing course syllabuses and their aims in an engineering school in the area where the participants work, i.e. Hong Kong. Where these skills were not clearly identifiable (as was the case in Management, Project Work and Design) from the documents on engineering courses, the skills suggested in the literature on these topics were allocated to the units.

For example, Mathematics requires the selection and execution of the most appropriate solution method, taking into account computer facilities
available; thermo-fluids requires problem solving and technical skills; design involves engineering fundamentals, analysis and presentation of technical information [Hong Kong, 1988]. In design creativity and critical thinking are not mentioned in the institutional course curricula. The literature, however, stresses these skills as essential for designers [SEED, p11, 1985; Banks, p6, 1983]. Therefore, these skills are allocated over and above the ones in the institutional course curricula.

The priority order for the nominated subject areas is extracted from Table 10 (p79) and shown below in Table 12 with the core mechanical engineering subjects grouped together and labeled Technical Subjects. These are ranked in ascending order here - as opposed to Table 10 (p79) where they are not.

In each of these academic units certain technical and interpersonal skills are inherent.

<table>
<thead>
<tr>
<th>Academic Units</th>
<th>Code</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management</td>
<td>MG</td>
<td>1</td>
</tr>
<tr>
<td>Engineering Design</td>
<td>ED</td>
<td>2</td>
</tr>
<tr>
<td>Computer Studies</td>
<td>CS</td>
<td>3</td>
</tr>
<tr>
<td>Engineering Drawing</td>
<td>DG</td>
<td>4</td>
</tr>
<tr>
<td>Mathematics</td>
<td>MA</td>
<td>5</td>
</tr>
<tr>
<td>Technical Writing</td>
<td>TW</td>
<td>6</td>
</tr>
<tr>
<td>Production Engineering</td>
<td>PE</td>
<td>7</td>
</tr>
<tr>
<td>Electrical Engineering</td>
<td>EE</td>
<td>7</td>
</tr>
<tr>
<td>Electronics</td>
<td>EN</td>
<td>8</td>
</tr>
<tr>
<td>Project Work</td>
<td>PW</td>
<td>9</td>
</tr>
<tr>
<td>Technical Subjects</td>
<td>TS</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 12: Nominated Subjects Ranking
The participants' nominated subjects (in detail with individual technical subjects listed separately) for a degree programme (Question 14 in Stage 3 of survey) is shown in Table 13.

<table>
<thead>
<tr>
<th>Subject Code</th>
<th>Subject</th>
<th>Subject Code</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Engineering Drawing</td>
<td>H</td>
<td>Thermo/Fluids</td>
</tr>
<tr>
<td>B</td>
<td>Engineering Design</td>
<td>I</td>
<td>Project Work</td>
</tr>
<tr>
<td>C</td>
<td>Mathematics</td>
<td>J</td>
<td>Manufacture/Prodn.</td>
</tr>
<tr>
<td>D</td>
<td>Technical Writing</td>
<td>K</td>
<td>Computer Studies</td>
</tr>
<tr>
<td>E</td>
<td>Management</td>
<td>L</td>
<td>Communications</td>
</tr>
<tr>
<td>F</td>
<td>Materials/Machines</td>
<td>M</td>
<td>Electrical Engng</td>
</tr>
<tr>
<td>G</td>
<td>Control Engng</td>
<td>N</td>
<td>Electronics Engng</td>
</tr>
</tbody>
</table>

Table 13: Participant Nominated Subjects List

The skills exercised (developed, in the case of educational programmes) in the use of these academic units in practice are taken from Harrisburger's skills list (see Figure 7, p47). These skills are coded for ease of operation and are listed in Figure 14.

<table>
<thead>
<tr>
<th>Code No.</th>
<th>Skills Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Problem Solving</td>
</tr>
<tr>
<td>2</td>
<td>Interpersonal Awareness</td>
</tr>
<tr>
<td>3</td>
<td>Creative Expression</td>
</tr>
<tr>
<td>4</td>
<td>Communication</td>
</tr>
<tr>
<td>5</td>
<td>Technical</td>
</tr>
<tr>
<td>6</td>
<td>Self Confidence Building</td>
</tr>
<tr>
<td>7</td>
<td>Computation</td>
</tr>
<tr>
<td>8</td>
<td>Engineering Fundamentals</td>
</tr>
<tr>
<td>9</td>
<td>Organisational</td>
</tr>
<tr>
<td>10</td>
<td>Leadership</td>
</tr>
<tr>
<td>11</td>
<td>Planning</td>
</tr>
<tr>
<td>12</td>
<td>Professional Ethics</td>
</tr>
<tr>
<td>13</td>
<td>Engineering Judgement (Critical Thinking)</td>
</tr>
</tbody>
</table>

Table 14: Skills Description and Codes

[Harrisburger, 1976, with modification in item 13]
In order to establish the priorities of skills utilised by the practitioners each subject area was allocated the relevant skills, limited to the ones proposed by Harrisburger. Such allocations were made using interpretation of traditional objectives of syllabuses developed in engineering schools and the definitions that were developed earlier in this chapter. These were extended to explain the definitions of the skills listed in Table 14.

For example, the descriptions and explanations in section on problem solving (p. 107-115) apply to skills numbers 1 and 13 in Table 14; the section on critical thinking and creativity (p. 116-127) apply to skills 1, 3, 8 and 13; Skills 2, 6, 10, and 12 are discussed in section on interpersonal skills (p. 128-134). Technical skills, code number 5, refers to the application of core discipline knowledge and is a pre-requisite for all engineers. Other skills listed (Communication; Computational; Planning; and Organisational) are self-explanatory and are required in most of the subject areas listed by the participants.

<table>
<thead>
<tr>
<th>Subject Code</th>
<th>Skills (see Table 14)</th>
<th>Rank*</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3,4,5,7,9</td>
<td>3</td>
</tr>
<tr>
<td>B</td>
<td>1,3,5,8,13</td>
<td>2</td>
</tr>
<tr>
<td>C</td>
<td>1,5,7</td>
<td>4</td>
</tr>
<tr>
<td>D</td>
<td>3,4,5,9,11</td>
<td>5</td>
</tr>
<tr>
<td>E</td>
<td>1,2,3,4,6,9,10,11,12</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>1,5,7,8,13</td>
<td>10</td>
</tr>
<tr>
<td>G</td>
<td>1,5,7,8,13</td>
<td>10</td>
</tr>
<tr>
<td>H</td>
<td>1,5,7,8,13</td>
<td>7</td>
</tr>
<tr>
<td>I</td>
<td>1,3,4,5,6,8,9,11,12,13</td>
<td>9</td>
</tr>
<tr>
<td>J</td>
<td>1,5,8,11,13</td>
<td>6</td>
</tr>
<tr>
<td>K</td>
<td>1,7,9</td>
<td>2</td>
</tr>
<tr>
<td>L</td>
<td>2,3,4,6</td>
<td>6</td>
</tr>
<tr>
<td>M</td>
<td>1,5,7,8,13</td>
<td>6</td>
</tr>
<tr>
<td>N</td>
<td>1,5,7,8,13</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 15: Skills Allocation (* participants' rank of subjects)
The skills allocated to each of the nominated subjects are shown in Table 15 in the coded form. From this table, the frequency of occurrence of each of the skills listed by Harrisburger in all of the subjects nominated by the participants is collated and the skills frequency is shown ranked in Table 16.

<table>
<thead>
<tr>
<th>Skills Code</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>11</td>
<td>26</td>
<td>5</td>
<td>12</td>
<td>3</td>
<td>8</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Ranking</td>
<td>29</td>
<td>56</td>
<td>1</td>
<td>8</td>
<td>3</td>
<td>3</td>
<td>6</td>
<td>10</td>
<td>7</td>
<td>9</td>
<td>4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 16: Frequency of Occurrence of Skills

The frequency of occurrence of skills indicates priorities of skills as perceived by professional practitioners. Technical skills are required in most subject areas and is rated the highest. Problem solving is the second most frequent skill needed followed by Computational Skills and Engineering Fundamentals. The value of Engineering Judgement is rated just higher than Creativity; with Planning and Self-Confidence Building skills next in order.

The priority that emerges from this tabulation and cross-referencing is listed in descending order:

1. Technical Skills
2. Problem Solving
3. Computational Skills and Engineering Fundamentals
4. Engineering Judgement (Critical Thinking)
5. Creativity
6. Communications Skill and Organisational Skills
7. Planning Skills
8. Self-Confidence Building
9. Professional Ethics and Interpersonal Awareness

10. Leadership

Technical skills is directly related to core competence or level of discipline knowledge and is determined by the effectiveness of the teaching of the core subject; computational skill is attributed to mathematics and computer studies areas; engineering fundamentals is the general knowledge and awareness of the principles governing engineering materials, machines and systems; and planning and organisational skills are essentially management skills.

Thus, we are left with skills that are not directly attributable to any academic unit wholly. Some of these are cognitive skills that a design engineer is required to have and some skills are of a social and interpersonal nature. These two sets of skills are:

\textit{Group A}

1. Problem Solving
2. Engineering Judgement (Critical Thinking)
3. Creativity

\textit{Group B}

1. Communication Skills
2. Self-Confidence Building
3. Professional Ethics
4. Interpersonal Awareness
5. Leadership

2.2 Skills from Concept Mapping

A summary of skills that emerged from the concept mapping exercise with undergraduate engineering students is listed in Chapter 5, pages 103-
The conclusion was that the skills discrepancies related to three distinct fields:

a) Information Technology;
b) Languages; and
c) International Trade and Relations.

All the other listed attributes are definable by Harrisburger's list (Figure 7, p47). Examples of this amalgamation are given on page 105-106, Chapter 5.

Information Technology has, in recent years, become a recognised subject in its own right. It is also the focus of much political, economic and public interest. The subject deals with information systems and is synonymous with computers and telecommunications. It is evident that employment trends in the USA and the UK show a marked shift towards information related sectors [Zorkoczy, p5, 1985]. In engineering, Computer Aided Design and Manufacture or Computer Aided Engineering and intelligent robots are commonly in use now.

This technology is essentially only a tool to enhance the engineer's creativity. Proficiency in searching for information (information storage and retrieval) is an asset to the professional.

Languages and international trade and relations are part of the general topic of communication and management skills.

3. Interlinking Skills Model

The skills that have now been identified as a paradigm for professional engineering design practitioner are:

Cognitive Skills

1. Problem Solving
2. Engineering Judgment
3. Critical Thinking
4. Creativity
Interpersonal or Social Skills

1. Professional Ethics/Integrity
2. Autonomy/Leadership
3. Self-efficacy/Self-confidence

The prerequisite for an engineering profession is, of course, the core knowledge of the discipline. The higher the level of competence in engineering science greater the possibilities to relate this knowledge to unfamiliar situations [Estrin, p53, 1963]. While this knowledge cannot be strictly termed a 'skill', it is nevertheless an important element in the matrix of cognitive skills that constitute a designer's pool of skills.

From a review of the theoretical and empirical literature [SEED, 1985; Banks, p4-6, 1983; Long, p201, 1983], the skills list that emerged from the practitioners, and the data from the concept maps of engineering school undergraduates, a matrix of skills and knowledge (adapted and modified from Harrisburger [1978] and Long [1983]) is proposed in Figure 14. The matrix has two main components:

- a technical and professional competencies section; and
- an interpersonal/social skills section.

The individual elements in this matrix are all interrelated and interdependent. As stated at the start of this chapter (p 107), these skills must be understood as a unified whole especially for curriculum development.

To achieve this understanding, propositional statements are deduced to illustrate the relationships between the elements.

Propositions are untested relationships which help to describe reality and precede a hypothesis (which is testable). These propositions, however, contribute to the understanding of the matrix model which is neither provable nor testable by accepted rules or scientific evidence or proof.
SKILLS INTERACTIONS FOR ENGINEERING DESIGNER

Figure 14: Skills Matrix Model
(Adapted and modified from Harrisburger [1978]; Banks [1983]; Long [1983])
Within this context fourteen propositions (adapted and modified from SEED, [1985]; Banks, [1983]; Long, [1983]; Harrisburger [1978]) are formulated relating the elements in the matrix as shown in Figure 14. The element interlinking numbers are propositional statement numbers.

1. Technical problem solving ability is dependent on knowledge of discipline subject matter.

2. Engineering judgement is influenced by the awareness and understanding of upto-date knowledge in the discipline.

3. Critical thinking is a generic skill and can be transferred across all subject areas.

4. Greater the ability to think critically, greater the ability to solve problems.

5. In engineering practice critical thinking affects the accuracy of engineering judgement.

6. Engineering judgement mediates between the engineer and the constantly changing environment.

7. Accuracy of engineering judgement and perception increases problem solving abilities.

8. Problem solving is significantly dependent on acquired skills, which are a result of the designer's previous experience and interactions with his environment.

9. The more creative the designers, more autonomous they are and the greater their ability to lead.

10. Creative designers are self-confident persons and are able to organise and execute courses of action to achieve set goals.

11. Designers with a sense of responsible autonomy are able to make decisions and cope with the consequences of their actions.

12. Higher the level of integrity, greater the perceived autonomy of the engineering designer.

13. Self-confidence breeds autonomy and fosters leadership qualities.
14. (a) Logical and critical thinking are related to ethics and moral standing of the engineering designer.
(b) Greater the critical thinking ability, the greater the autonomy of the engineering designer.

4. Refinement of Interlinking Skills Model

The model developed is all-encompassing - in terms of skills and attributes for a design engineering professional. It describes all the areas that need to be addressed for a complete professional education. It is, however, too complex to extract any clear directives for a design course curriculum - which is the main objective of this research. The difficulty arises in the interaction between the social skills and the technical competence areas.

It was, however, established in Chapters 2 and 3 that design is essentially a problem solving task (see p. 48). It was also shown that the skills listed by Harrisburger [1976] relate closely with the attributes needed in the professional (see p. 50). The cognitive competence was shown to be important and the different cognitive skills discussed in detail earlier (Chapter 3, p. 51 and Chapter 6, p. 107-128).

Therefore, there was a need to refine this model to highlight the directives for curriculum design from a cognitive skills development aspect - in the knowledge that other courses in the undergraduate programme would cater for some of the social and interpersonal skills.

This does not imply that social and interpersonal attributes are neglected in the design curriculum. The literature on engineering education - and indeed all professional education - indicates clearly the need for developing these skills in the undergraduates. This need permeates the design of all educational courses. The selection of content of an engineering course is not a relatively isolated activity, as is often
considered by engineering educators [Grayson, 1977, p. 75]. In the organizing of a curriculum, Grayson goes on to say:

'... because mastery of subject matter is not regarded here as an end in itself. Rather, the subject matter is studied to achieve certain ends. What the student learns is specified by the goals that are set and the objectives that are derived from them. This is probably the most important part of curriculum design, and all too often is the most neglected.' [ibid., p75]

Therefore, the matrix in Figure 14 together with the above fourteen propositions were used in a survey to refine them prior to acceptance as a base for curricula development in engineering design - to highlight especially the development of cognitive skills. The sample of the documents used in the survey are shown in Appendix N.

The survey sample was limited to twenty - nineteen professional engineers and one student engineer. Of the nineteen engineers, ten were from industry and the remainder from tertiary engineering institutions. The student in the survey was selected because of the level of maturity and understanding this particular student had displayed during the concept mapping stage of this work.

Each participant was sent a copy of the model, the fourteen propositions and definitions of the attributes and skills in the model as a guide line and a starting point.

A cover letter requested them to study the model and the interactions; use the definitions as given or consider their own. Review the model with the given or their new definitions and consider the suggested propositions. They were then asked to feel free to alter, modify, rearrange the items and the interlinks to suit their views. They were asked to look for any errors, misleading statements, understatement, overstatement in either the model or
the propositions.

Addressed return envelopes were sent with the package and assurance was given as to the confidentiality of the survey.

While most of the survey was done by post, six academics and a student were interviewed personally. The general result, in terms of positive response, of the survey was rather disappointing. Eleven were returned with statements generally agreeing with all that was proposed. Such a return is probably indicative of either the overwhelming complexities involved in defining concepts of skills and attributes or the understandable lethargy among practitioners in such seemingly abstract work. One participant confessed that:

'Judging by common sense, all you have said must be correct. But for any refinement of the model one must need (have) the knowledge of psychology, which I lack.'

(my word in parenthesis)

One academic summed up the whole matrix into one word - Experience. Others related problem solving to a matter of 'knowing what to look for' and 'keeping the learning curve vertical'. A common philosophy was to tackle problems from first principles.

Some questioned the separation of creativity from other skills. They felt creativity should be diffused into the whole model. Many asked for more details regarding the nature of the research work and were not able to define precisely some of the technical competencies elements, like problem solving and engineering judgement.

One engineer had a solution to the whole problem of education of the engineering designer. He wrote, in response to the survey:

'At a lecture entitled "How to Win a Nobel Prize" given by a Nobel Prize winner, the lecture theatre was crammed to overflowing. All he (the lecturer) did was to put up a family tree of Nobel prize winners and show that most
of them had studied under older Nobel prize winners - the master/apprenticeship relationship. Find a good designer and stick to him!

The same engineer also commented that students should know ‘who to ask’ and ‘what to ask’. Communication ability was questioned by some with respect to proposition 9. Leadership qualities were linked to propositions 10, 11 and 12.

Innovation was often substituted for creativity in engineering. One academic felt that the fragmentation of skills as shown in the model was not a reflection of real-life situation. He felt that the engineer should be viewed holistically.

The student who was interviewed produced some interesting comments. He felt problem solving required a ‘procedure’ starting with getting information to optimising the final solution. He felt critical thinking may not give the optimum solution - because the customer may not pay for this optimum solution. Some of his other comments were:

‘...without basic knowledge you can’t recognise importance of skills’

‘...critical thinking is a range of thinking... technical thinking...’

‘...if you are eager to learn, all subjects provide critical thinking opportunity.’

‘... always find out some method to make problem easier to solve or sometime completely solve them.’

Another engineer commented that there were:

‘... many engineers in the UK without ... discipline knowledge.... intuitively knew .... by the seat of their pants....designed systems ....’

‘Design manuals now give you everything you want. But wisdom comes from experience...’

It was clear that the model in Figure 14 was complex and the
interlinking was not clear and in some cases, confusing to the practising engineer.

The comments focused on the artificial separation of the technical and social skills into two distinct parts. The environment also plays an important part in the education process and needed to be highlighted as a stimulus source to foster the desired skills in the engineer. Literature search also indicated that the environment has a strong influence on the social skills of the professional. Houle [1987] has addressed this aspect in detail (also see this Chapter, section 1.2; see p 128-134) particularly with reference to professional schools.

Based on these statements and findings the model was refined to reflect some of the views expressed by the sample population. This new model is shown in Figure 15 (p. 150). In this, the interpersonal and social skills surround the engineer rather than as a separate sets of skills. The fragmentation is thus avoided and a more complete view develops. These social skills are also moulded by the environment in which the engineer lives and works.

The technical competencies are central to his effectiveness and are therefore placed at the heart of the model. Creativity is no longer isolated but involves all of the core knowledge and other cognitive skills such as critical thinking, engineering judgement and problem solving.

Added to this model are the skills that were identified by the beginners in the profession - the students. These are labeled Information Technology, Communication and Languages (see p102-106). The influence of these elements on the formation of an engineering designer is dependent on the level of socio-economic status and development of the territory in which the institution operates and the future needs of its industries.
Interpersonal and social skills domain

Technical Competence

Core Competence
Discipline Knowledge

Engineering Science

Critical Thinking

Problem Solving

Engineering Judgement

Cognitive Skills Domain

Creativity

Information Technology/Communication/Languages

Figure 15: Skills Matrix Model (Revised)
Artificial Intelligence and expert systems will no doubt be the essential tools of the designers of tomorrow and information technology is the initial step in this direction. From a creativity angle, this must be viewed as a skill worth developing. These three elements directly support all of the cognitive skills and the technical core knowledge competence.

These are also essentially dynamic areas and will continually change during the life of the professional. Therefore, much of this is related to continuing education of professionals. At an undergraduate level, an awareness and sound appreciation of these is essential to the career development of the professional.

5. The Skills Matrix Model (Revised)

As stated previously, the basic aim of this matrix model is to direct curriculum development. To understand the relationships between the new set of elements in the matrix, some further propositions are formulated and are schematically represented in the revised model (Figure 15, p. 150).

The numbers in the model refer to the propositions that are postulated below. The arrowed lines lead from a knowledge or skill base to an operational domain. For example, core discipline knowledge forms the basis of developing an ability to solve problems in the discipline. Therefore, the arrowed line starts from the engineering science base and leads to the operational problem solving block.

Creativity is enhanced by both the technical competence and the interpersonal skills of the designer. It is also influenced by the quantity and quality of information available to the designer and his general skills in communications. This is a dynamic situation and is shown in the model as an interaction of interpersonal skills and the technical skills through the
environment in which the designer operates in.

The model also supports clearly the view that creativity cannot be dealt with at a single level of explanation [Gardner, 1983] (see p. 120). It interacts with all the cognitive skills and the social attributes and is shown as such in the revised model.

The six propositions relate to the technical competence elements (the cognitive skills domain) - Core Knowledge (Engineering Science); Critical Thinking; Problem Solving; and Engineering Judgement. The propositions are derived from statements and comments made by the group involved in assessing and refining the first model. The propositions are:

1. A pre-requisite to problem solving is a knowledge of subject matter relevant to the particular discipline.

2. Critical thinking is a generic skill; it is independent of any particular subject area.

3. Engineering judgement is influenced by awareness and understanding of up-to-date knowledge in the discipline.

4. Greater the ability to think critically, greater the ability to arrive at an optimum solution to the problem.

5. In engineering practice critical thinking affects the quality of engineering judgement.

6. Quality and accuracy of engineering judgement and perception increase problem-solving ability and vice versa.

Creativity is subsumed in the six propositions since effective methods of fostering and stimulating creativity are problem-solving activities. This is supported by the literature as discussed in Chapter 6 (p. 120-128).

The strength of the model is its clear indications of interactions. The task of deriving curriculum directives from the model are relatively simpler than through the original model.

Curriculum design also requires statements of educational strategies
with reference to the objectives. Thus, while this model and the derived propositions help in the understanding of the many interactions and interdependence of the elements in the matrix, any curriculum emerging from this must be based on the educational strategies that have been identified to develop these skills in the professional engineer.

The next chapter considers the theoretical underpinnings of curriculum design. Following this study, details of a scheme for engineering design at the undergraduate level using the above model and the propositions is developed.
Chapter 7

Model Curriculum for Engineering Design

Introduction

In the previous chapter a skills interaction matrix model was developed to guide the structure of a curriculum for the education of an engineering designer. In engineering schools, particularly in the USA, curriculum developers have generally focused on what a student should know, to the exclusion of how he learns the skills necessary for effective professional practice. Much of this was carried out intuitively and more as an art than by any scientific methods. Harrisburger put it quite aptly:

'Most of us who have been in higher education for a number of years operate as rank amateurs when it comes to having a background in educational techniques' [p. 4, 1976]

Learning, however, is a slow process. Very seldom does a single learning experience have a profound effect on a student. There is a cumulative effect [Gagne, p.152, 1977] in learning caused by changes over a period of time in ways of thinking, in fundamental habits, in skills, in major operating concepts, in attitudes and interests [Grayson, p. 77, 1977]. The educational experience must cater for this cumulative effect in learning. Furthermore, professional educational schools set out to provide a formal education in a vocational activity restricted to a specific discipline - skills attributes necessary for the particular profession are developed in the beginner.

The curriculum is the primary medium through which this is facilitated and it is the instrument through which the various elements of the educational environment - the student, the society in which he lives and works and the educational process - are fused to provide an experience that
prepares him for a professional life. The theoretical underpinnings of the discipline of curriculum, must therefore, provide some clues to the direction for valid educational decisions.

1. The Concept of Curriculum

A curriculum is an organised course of study undertaken by a student in or under the aegis of a college, school, university or other institute of learning. More commonly it refers to the set of studies organised for a particular group of students (e.g. an age-group) by an educational school or other similar institution [Page, p95, 1979]. Many other definitions are derived from its Latin root 'currere', which means 'to run'. At the higher education level what is usually meant by the curriculum is 'all the courses offered, considered as a totality,' or 'all the courses taken by some person one after another' [Chickering et al, p. xiv, 1977].

In reviewing curriculum models, William Berquist [ibid., p. 83-84] combines various proposed models to produce 'The Curricular Circle' shown in Figure 16.

Figure 16: The Curricular Circle

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The left hand side of the Circle reflects a dominant concern for generality; the right for specialisation; the top for prescription; and the bottom for elective bias where students have primary control over the content of the curriculum.

This representation of curricular dimensions is comprehensive. However, the eight categories shown are not homogeneous in that some relate to curriculum content; others to the way in which decisions are made about the curriculum; and some to the way in which students learn. The model suffers from a lack of elegance. Five dimensions are suggested by Berquist [ibid., p. 85] to be added, as shown below, to refine the Circle further.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) curricular breadth</td>
<td>experiential/problematic/regional;</td>
</tr>
<tr>
<td>b) curricular control</td>
<td>student/faculty/department/institution;</td>
</tr>
<tr>
<td>c) instructional process</td>
<td>lecture/tutorial/experiential;</td>
</tr>
<tr>
<td>d) curricular structure</td>
<td>credit for experience/modular/self-paced;</td>
</tr>
<tr>
<td>and e) curricular outcomes</td>
<td>knowledge/awareness/skills.</td>
</tr>
</tbody>
</table>

Learning also directly affects curriculum decisions. Chapter 3 (p. 42) looked at learning in general. In the engineering schools, however, the entrant to the professional school is minimally eighteen years of age while students in a course are in the 18-25 years age range. In Hong Kong the entrant is likely to be between 19 and 21 years old with some (about 0.5%) between 28-33 years of age - i.e. they are young adults [SAU, p. 1, 1987].

As such, the characteristics and implications of adult learning theories are relevant in making curriculum design decisions. As students mature, sharp contrasts develop between their present and their childhood learning styles and methods.
As an adult the self-concept of an engineering student is changing from one of dependent personality to one of being a self-directed human being. He is willing to make his own decisions and accept the consequences. Adults tend to resist learning under conditions that are incongruous with their self-concept as autonomous individuals [Grayson, p. 94/95, 1977].

Motivation is the cornerstone of adult learning theory [Brody, p.39, 1985]. Rogers [1961] and Fromm [1955] contend that a positive motivating force is self-fulfillment. Maslow [1968] proposes a hierarchy of human needs which adults strive to meet. Some of these implications in adult learning in recent theories discussed by Grayson [1977] and listed by Knowles [1978] are shown below:

<table>
<thead>
<tr>
<th>Characteristics of Adult Learners</th>
<th>Implications for Adult Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. The adult learner sees himself as capable of self-direction and desires others to see him the same way.</td>
<td>1 (a) A climate of openness and respect is helpful in identifying what learners want and need to know. 1 (b) Adults enjoy planning and carrying out their own learning exercises. 1 (c) Adults need to be involved in evaluating their own progress towards self-chosen goals.</td>
</tr>
<tr>
<td>2. Adults bring a lifetime of experience to the learning situation. Youths tend to regard experience as something that has happened to them, while to an adult, his experience is him. The adult defines who he is in terms of his experience.</td>
<td>2 (a) Less use is made of transmittal techniques; more of experimental techniques. 2 (b) Discovery of how to learn from experience is key to self-actualisation. 2 (c) Mistakes are opportunities for learning. 2 (d) To reject adult experience is to reject the adult.</td>
</tr>
</tbody>
</table>
3. Adult developmental tasks increasingly move toward social and occupational role competence and away from the more physical development tasks of childhood.

4. Youth thinks of education as the accumulation of knowledge for use in the future. Adults tend to think of learning as a way to be more effective in problem-solving today.

3 (a) Adults need opportunities to identify competency requirements of their occupational and social roles.

3 (b) Adult readiness-to-learn and teachable moments peak at these points where a learning opportunity is coordinated with a recognition of the need-to-know.

3 (c) Adults can best identify their own readiness-to-learn and teachable moments.

4 (a) Adult education needs to be problem centered rather than theoretically oriented.

4 (b) Formal curriculum is less valuable than finding out what the learner needs to learn.

4 (c) Adults need the opportunity to apply and try out learning quickly.


In the design of a curricula for engineering design, both the characteristics of and the implications for the adult learner must be considered at all stages if learning is to be encouraged. The major consequence of this approach is the emphasis on human effort and motivation in the various elements in the curricula. The involvement of the learner in the curriculum system design from the beginning of a course is a deviation from the norm.

It is obvious from an inspection of current curricula in engineering design (see Appendix P, for example) that no attention is paid to any learning theories - let alone adult learning theories. The model that is
developed now incorporates the basic adult learning characteristics and their implications as listed above.

The numeric references shown in the above adult learning characteristics will be cited in the curriculum details for design education that is developed later in this chapter. This cross-referencing will link the curriculum items with the relevant sections of the above listing.

2. Curriculum Model for Engineering Design

2.1 Overview

The general discourse on engineering education, the review of design education and the literature research on the education for professional competency (Chapters 1, 2 & 3) concluded that design education should emphasise the development of skills and attributes required for effective professional practice. These skills and attributes were identified and the skills model evolved (Chapters 4, 5 and 6) to direct curriculum planning.

Having identified the skills needed for the effective practice of engineering design, the next step is to provide the educational experience to develop these skills. Some of the theories of curriculum design are seen as inappropriate for this level of academic work while others tend to be more suitable for analytical work at any level, as shown later in this chapter.

It was established earlier (Chapter 3) that, on the most general level, the cognitive model (Figure 5, p 38) as proposed by Bloom [1956] is applicable in the education of the design engineer, i.e. the goals and objectives of the curriculum are primarily cognitive and goals in this domain deal with learning intellectual knowledge and skills. This level of instructional design is sometimes referred to as the macro-level
Adopting Gagne and Briggs’ (1979) "top-down" approach to designing instructional programmes, the skills that have been identified (Chapters 4 & 5) serve as the broad general goals and objectives of an engineering design curriculum. These objectives can be further analysed and sequenced at various levels. For example, taking the right half of the Curricular Circle (Figure 16) and adding a curricula outcome dimension to this gives a set of performance objectives - the specific learning outcomes expected. These can be broken down to enabling objectives each of which may have several sub-ordinate objectives. These enabling objectives can be sequenced and instruction strategies can be designed for individual skill or attribute.

Many sequencing strategies are suggested in the literature. There are, however, five main organising principles, as summarised and suggested by Reigeluth (1987, p.182)

1. World-related sequences - the consistency and relationships among phenomenon as they exist in this world;

2. Conceptual-related sequences - the organisation of the conceptual world as it relates to the real world;

3. Inquiry-related sequences - those that derive from the nature of the process of generating, discovering or verifying knowledge;

4. Learning-related sequences - based on knowledge of the psychology of learning; and

5. Utilisation-related sequences - either through procedural sequences for problem solving or based on the utilisation potential of the content.

In each of these there are a variety of sequences, generally in a progressive simple-to-complex sequence. Some common varieties are the
Spiral Curriculum [Bruner, 1966], Ausubel's Progressive Differentiation [1963], and Gagne's Hierarchical Sequence [1985].

It can be argued that such a linear sequence is very suitable logic for analytical purposes but in engineering design there is an interactive relationship as shown in the matrix model (Figure 15). The real world situation cannot be so tightly sequenced or ordered.

Existing courses in engineering schools also do not give a unified view of the curricula for engineers. A study of design courses at various British Universities (five) and Polytechnics (four) carried out by Koroma [1986] concluded that:

'For effective design studies a minimum of 15% contact time is recommended' [p. 144]

'Though there were dissimilarities between curricula surveyed and those in the literature (but) the objectives of the courses appear to be the same.' [p. 143]

'There are unique features highlighted which can be experimented with on any course in an attempt to find an optimum blend.' [p. 143] (my italics, not original).

It is obvious that the institutions need to research and develop a body of knowledge in this area. Very few, if any, engineering schools appear to devote any resources to this. Bement [1985] reviewed nine degree programmes at different British Universities and Polytechnics and reported that only one institution (Trent Polytechnic) looked at Engineering Education as a research area.

It is also evident that curriculum designers, in engineering design, while realising the 'importance of sequencing of instructions which influences the stability of cognitive structures and thereby influencing long term retention and transfer' [Ausubel, 1963] have found it difficult to produce such sequenced programmes. Levels of proficiency must be made
gradually increasing in difficulty in order to enhance learning and retention.

One exception to this is the work done by Bussard [1982]. In a 3-year project at Cooper Union, New York, the aim was to improve students' abilities to perform competently as professional engineers. In the context of engineering education, the skills considered for competence by Bussard are similar to the ones that have been identified in this research. The programme, however, only covers engineering in general and does not examine design as a separate issue.

Problem solving, in the cited work, appears to encompass engineering judgement, creative and critical thinking - although this is not stated. Interpersonal and social skills are classified as value clarifications. Communication covers all aspects of oral, graphical and other media for information sending and receiving. Three levels of proficiency are used in the Bussard project, each more sophisticated than the previous level.

2.2 Directives for Design Curriculum

The three main directives for the design of the curriculum in engineering design that follows are:

- the objectives of the course;
- the levels of proficiency expected of the student; and
- the resources and means of instruction.

a) Objectives

The matrix model of the professional engineer makes it possible to design a professional curriculum based on the technical elements, the interlinking propositions, the supporting technologies and skills, and the social skills that appear in it. The core competence in subject matter is
decided by the discipline and the level of the award.

Objectives for the design curriculum, as stated earlier, are development of the skills identified in this research. The curriculum can be stated in terms of the various elements in the skills matrix model. The beginning professional will be expected to:

1. Use critical thinking skills to identify or recognise problems related to his field of study, collect and collate necessary data and information and make accurate engineering judgements.

2. Synthesise knowledge from his discipline, the sciences, arts, and humanities to observe, absorb and analyse environmental cues and employ appropriate problem solving strategies.

3. Be prepared to cope with constantly changing environment and technology and view previous experiences from new perspectives creatively.

4. Be prepared to master new technology and understand its impact on his profession and its utility.

5. Practice his profession within its framework of the code of ethics/practice.

b) Levels of Proficiency

From the study of engineering courses in the UK [Koroma,1986 for example] it is clear that courses are either of a three year duration for the BSc (Eng) type or a four year sandwich type for the BEng award. Both imply, however, a three year academic experience in an engineering school. With this format, three levels of proficiency for each of the skills would enable the curriculum to build in course work that progressively increases in sophistication and difficulty.

From the review of the literature (see Chapter 6) on the various skills that make up the matrix model and also adopting the three levels of proficiency, directives for curriculum design are generated using a deductive approach.
The levels and their directives for curriculum design are listed below for each of the skills.

**Problem solving and Engineering Judgement** (see p107-116)

Level 1: Demonstrate ability to formulate assumptions; identify implicit and explicit elements in order to apply simple and common principles; adopt appropriate methodologies to generate realistic solutions.

Level 2: Analyse new problems and relate to similar ones from experience; identify interaction of elements in the system; synthesise alternative designs; carry out project work within well-defined field; arrive at conclusions.

Level 3: Show a positive orientation towards interdisciplinary and innovative ideas; exhibit critical thinking; synthesise alternative solutions and strategies; demonstrate executive powers.

**Critical Thinking** (see p116-120)

Level 1: Demonstrate powers of observation, ability to generalise, conceive and state assumptions.

Level 2: Ability to reason and consider problems in a thoughtful way; appraise evidence and evaluate designs in a logical manner; render accurate judgement about specific things.

Level 3: Ability to integrate new learning in its particular domain of knowledge or experience and establish cognitive routes and analogies between the new and previously learnt knowledge or experience; show a widening and deepening of interest in human affairs; develop a sense of nuance and the qualitative (to counterbalance the quantitative technical education); recognise and appreciate the effect of engineering design on the ecological, social and cultural status of the society in which artefacts and systems operate.

**Creativity (or Creative Thinking)** (see p120-128)

Level 1: Ability to recognise a need and define the boundaries for design on his own;

Level 2: Ability to envision and formulate numerous alternatives and solutions featuring new and feasible features to satisfy the function and need;
Level 3: Strong and positive orientation towards new and innovative ideas; lateral-thinking ability; tolerance for divergent views; high level of fluency, flexibility and originality.

In the support areas of Information Technology, Communications and Languages, the following proficiency levels are proposed by the researcher based on Section 3 of adult learning characteristics as listed earlier in this chapter (p. 157-158) and the analysis and refinement of the matrix model in Chapter 6 (p. 145-153).

**Information Technology/Communications/Languages**

Level 1: Demonstrate ability to receive and transmit technical information through oral, written, graphical and other media in a clear, accurate and neat format. (In this level emphasis is on the psychomotor skill, coordination, computational accuracy, use of computer graphics and development of self-confidence - in academic exercises.)

Level 2: Ability to prepare and present a comprehensive design assignment to peer group and faculty audience in a formal atmosphere; ability to prepare clear and logical technical reports relating to his discipline.

Level 3: Ability to employ all necessary techniques to communicate his ideas and concepts to a professional audience. (Emphasis here is on organisation and presentation of technical subject matter - particularly design of an artefact, process, or system.)

**Interpersonal and Social Skills** (see p128-135)

These levels are in a continuum and should be viewed as a maturing process in the student during the course.

Level 1: Identify personal values and their sources as they relate to a specific situation by self-analysis. (Emphasis here is on observing one's own feelings, thoughts, beliefs, ambitions and morals.)

Level 2: Demonstrate an understanding of the engineer's code of practice; exhibit autonomy in coursework.

Level 3: Ability to lead/follow and contribute in group projects; deal confidently with unpredictable, ambiguous and stressful situations.
c) **Source of Instruction**

The above two directives for curricula design, the objectives and levels of proficiency, are the desired results of a course - achieved by the selection of suitable learning activities. Here certain general principles apply to the selection of learning activities. These are self-evident when they are stated. When they are violated it is usually because they are not consciously in the mind of the curriculum developer [Grayson, p. 99, 1977].

As stated in Chapter 3 (p. 42) learning is one of the major areas of research and investigation in psychology and is the centre of a great deal of controversy. The following general principles are quoted in the literature as guidelines in selecting learning activities for educational curricula.

1. For a given objective to be achieved, a student must engage in activities that give him an opportunity to practise the kind of behaviour implied by the objective.

   *(Thus, for problem solving skills in engineering design, the activities must deal with design problems)*

2. The learning activity must give the student satisfaction from carrying out the behaviour implied by the objectives.

   *(Establishing the student's needs and interest is an important factor)*

3. The reactions expected from an activity must be within the range of the student's current abilities.

   *(Levels of proficiency must be graded through the course and the student's present knowledge must be known)*

4. There are many activities that can be used to bring about the same learning.

   *(It may not be necessary to prescribe specific activities - the choice may be left to the staff or students to select appropriate methods from an available range in some cases)*
5. It is possible that some learning activities may bring about several outcomes.

(Economy of time possible by careful choice of activities to generate several outcomes from each one. A negative aspect is that staff need to watch out for undesirable outcomes in certain cases)

The learner and the objectives of the curriculum are thus articulated by the learning activities and instructional methods employed. The methods provide the experiences for the learner to achieve the levels of proficiency expected. The methods chosen are based on a number of criteria, including the general principles given above, the characteristics of the student, number of students, content of the syllabus, practice and feedback requirements, availability of resources, and faculty skills or speciality.

Several methods of instruction are available to the curriculum designer. Eight instructional approaches are shown in Figure 17 (modified from Reigeluth [p.200, 1987]) as defined by source and receiver of the instruction.

A more comprehensive list (see Figure 18) with a guide to the selection of various approaches, according to specified conditions, is again taken from Reigeluth [p.201, 1987] and modified to suit the teaching of design. It is used as a reference in subsequent work on the details of the curriculum.

Literature research revealed specific techniques that have been found useful in certain problem solving situations and these are illustrated in Figure 19. During the next stage these were consulted, when needed, and used as a guideline in the selection of specific instructional and learning techniques.
<table>
<thead>
<tr>
<th>Human</th>
<th>Non Human</th>
<th>Instructionally Designed Environment</th>
<th>Instructionally Not Designed for Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non Professional</td>
<td>Professional</td>
<td>Individual Projects</td>
<td>Individualised Resources</td>
</tr>
<tr>
<td>Individual</td>
<td>Group</td>
<td>Peer Group Interaction</td>
<td>Group Discussions</td>
</tr>
<tr>
<td>Selection Criteria</td>
<td>Individualized Instruction</td>
<td>Group Activities</td>
<td>Lecture or Demonstration</td>
</tr>
<tr>
<td>--------------------</td>
<td>-----------------------------</td>
<td>------------------</td>
<td>-------------------------</td>
</tr>
<tr>
<td>Practice and Feedback Requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not required</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Note practice required</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Immediate, individual feedback needed</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perspectives/attitudes of peers important</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Responses difficult to evaluate</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide range of responses possible</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Evaluation/practice conducted in natural environment</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Content Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Abstract/complex information</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urgency/changing information</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low priority information</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Easy to retain</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No/low active participation of learner required</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Problems with no clear answer</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Special presentation for special group</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unique task for one/few learners</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Homogenous</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Similar verbal/analytical aptitude</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Above-average intelligence</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low achievers</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Need to alleviate anxiety caused by group work</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Need affiliation with teacher</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Need affiliation with peers</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Can work independently</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teamwork Requirements</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Real-life team task</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interactive skills critical to task</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group consensus needed</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student cooperation/group cohesiveness sought</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resource Considerations</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Large number of students</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
<tr>
<td>Lack of teachers/money/materials</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Individual records to be managed</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>

Figure 18: Guidelines for selecting an instructional approach (Modified from Reigeluth and Curtiss, p.201, 1987)
<table>
<thead>
<tr>
<th></th>
<th>Techniques*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(●-Established; X - Possible)</td>
</tr>
<tr>
<td>Environment</td>
<td>1 2 3 4 5 6 7 8 9 10</td>
</tr>
<tr>
<td>Engineering</td>
<td>● ● ● ● ● ● ● ● X</td>
</tr>
<tr>
<td>Design &amp; Innovation</td>
<td>● ● ● ● ● ● ● ● ●</td>
</tr>
<tr>
<td>Product Managers</td>
<td>X X ● ● ● ● ● ● ●</td>
</tr>
<tr>
<td>Technical Managers</td>
<td>● ● ● ● ● ● ● ● ●</td>
</tr>
<tr>
<td>Think Tanks</td>
<td>● ● ● ● ● ● ● ● X X</td>
</tr>
<tr>
<td>Value Analysis</td>
<td>● ● ● ● ● ● ● ● ●</td>
</tr>
<tr>
<td>Frequency:</td>
<td></td>
</tr>
<tr>
<td>Established Techniques</td>
<td>5 3 3 4 6 6 4 5 4 4</td>
</tr>
<tr>
<td>Possible Techniques</td>
<td>1 1 0 0 0 0 0 1 1 1</td>
</tr>
</tbody>
</table>

* Restructuring Techniques
1. Morphological Analysis
2. Relevance System
3. Attributes Lists

* Decision Aids
4. Weighting Procedures
5. Check Lists

* Brainstorming
6. Osborn's Method
7. Trigger Sessions

* Synectics
8. Goal Orientation
9. Excursion Procedures
10. Individual Synectics

Figure 19: Applicable Techniques for Engineering Design Education
(Adapted from Rickards [p.5, 1982] and modified)
Specification of instructional requirements should take into account the three different groups involved - the designer, the deliverer, and the recipient. Each institution needs to identify its own idiosyncratic requirements. There can be no single master blue-print of instructional package that can be universally applied.

The skills matrix model, the objectives of the curriculum, and the proficiency levels derived in this research are intended to be universally applicable. Together they can form the basis and provide the directions for the development of a curriculum in engineering design.

An example of such a curriculum development is now presented to test and highlight the universal applicability of the proposals.

2.3 Engineering Design Curriculum

The Environment

A hypothetical undergraduate engineering design course is considered in the application of the curriculum design directives as developed earlier in this chapter, section 2.2. Design teaching activities in the first year of an engineering course are taken as an example.

A visual inspection of design teaching activities of various 3 or 4 year courses indicates very clearly that the first and last years of the course account for the bulk of the hours [Koroma, p.139, 1986]. The table showing the patterns of teaching activities in the courses reveals, not surprisingly, the universal teaching of engineering drawing (not yet referred to as Graphical Communications in the institutions studied in the cited work) in the initial stages of the course and Projects in the final year. Machine design and design process appear to be generally tucked away in the middle years of courses [ibid., p 140-141].

It is clear from the literature search that design cannot be purified
and taught as a 'machine design' module in the middle years of an engineering course (see pages 29-30). The skills involved in design need to be fostered throughout the duration of the course with increasing levels of competence in the senior years.

The courses in various universities that were analysed by researchers and reported in the literature [Koroma, 1986; Cross, 1985; French, 1981] do not include any competency objectives in detail. Where some cursory information exists [Hong Kong, 1988], details on teaching strategies adopted are missing. It would, therefore, appear that instructional modes are arbitrarily used with no reference to any course objectives.

While competency objectives are common to all courses of similar levels, the selection of instructional modes will depend to a large extent on the facilities in the institution, the skills of the faculty, and the characteristics of the entrant to the course. In any exercise in applying the proposed schema for curriculum design, these aspects need to be ascertained at the start.

In the example that follows, the environment is the institution that the researcher teaches in and majority of the entrants are graduates of local secondary schools.

The institution is called the Hong Kong Polytechnic and was formally established on 01 August 1972 when the Board of Governors assumed responsibility for the new institution, taking over the campus and staff of the former Hong Kong Technical College. At about the same time the University Grants Committee of Hong Kong was reconstituted into the University and Polytechnics Grants Committee to bring the Polytechnic under the same administrative and financial control as the two universities in
The Department of Mechanical and Marine Engineering is one of 21 academic units grouped under seven Divisions. The Department has been running an Honours Degree programme in Mechanical Engineering since 1983 together with the traditional full-time Higher Diploma and the part-time Higher Certificate courses in Mechanical Engineering. The degree course is a design biased 4-year thick sandwich type.

The aims of the course [Hong Kong, 1988] are to provide education for the initial formation of professional mechanical engineers at honours degree level. To assist the development of a suitable curriculum, four main functions and four artefacts produced by the professional engineering practitioners in Hong Kong are identified:

- **functions:** Design; analysis; maintenance; and installation.
- **artefacts:** consumer products; machine components; manufactured components; and heavy equipment systems

Three aspects of learning are suggested to be provided in the curriculum:

Firstly, in terms of specific knowledge, the curriculum must be designed for the students to acquire:

- competence in applying basic principles of the mechanical core in design and analysis;
- knowledge in supportive engineering sciences for designing of engineering systems in which mechanical components play major roles and for co-ordinating projects that are multi-disciplinary in involvement;
- experience in experimentation and operation of equipment for testing and installation work;
- awareness of the business, management and social environments relevant to the engineer's work; and
- appropriate exposure to state-of-the-art developments in mechanical engineering technology.
The second aspect is detailed in terms of providing opportunities for practice in the adoption of a 'systematic approach' to problems, developing communication skills and 'working in groups'. Assignments are suggested to be 'commensurate with the student's capabilities'. Thirdly, faculty are required to show by example the 'extent of personal developments that are expected of a professional engineer'.

The Engineering Design course details are given in Appendix P and the following pages will relate the application of the directives developed in this research to this course.

To provide a set of guidelines for those working in the field a concise description of the directives is presented in a departmental report entitled:

'Guidelines for the development of a curriculum in engineering design'
by KK Chandran

Department of Educational Studies
University of Surrey
December 1988.

The details in the above report may be used generically as a set of specifications in the development of a curriculum for engineering education and in particular engineering design education.
The Curriculum

The existing syllabus now followed in an Honours Degree programme in Mechanical Engineering [Hong Kong Polytechnic, 1988] is taken as a sample case for this exercise and the 'Engineering Design' subject syllabus in this programme is reproduced completely for reference in Appendix P - as it appears in the course documentation.

An important factor in this course is that while the entrants to the course are secondary school graduates they have been instructed for two weeks (full time) in the fundamentals of engineering practice in an industrial environment - in the Industrial Centre of the Hong Kong Polytechnic.

This two-week induction course is a pre-requisite to entering the first academic year of the Honours Degree programme.

(It must be pointed out here that the degree course is currently going through revalidation procedures and may be altered or modified prior to implementation. At the time of this research work the syllabus used in the following exercise corresponded with the documented degree course syllabus.)

The course followed by the entrants in the Industrial Centre (of the Hong Kong Polytechnic) is titled:

'General Engineering Knowledge and Communication'.

The intentions of the course are to:

'... develop the students' knowledge and "feel" in engineering work. Throughout the training, students will be involved in systematic investigation of various types of engineering components and systems, so as to appreciate their function, design details, materials used, and methods of assembly. Also, this package is designed to develop the students' understanding in engineering terminology, and their skills in technical communication.' [Hong Kong, p. 22.3, May 1988]
The emphasis in the course is on the students self learning through practical investigation and retrieval of information, thus training the student to ‘think and find out for himself’ [ibid., p.22.3].

The key features as the course is taught are:

i) A Practical Design Appreciation Course:

The general aims of this course are to enable students to be familiar with terminology related to engineering materials, tools and equipment; have an understanding of design features of an assortment of heat engines and refrigerating equipment; understand the function and application of engineering components such as bearings, couplings, mechanical drives, fasteners, seals etc., and be aware of their design features and methods of assembly; understand industrial and practical applications of pneumatic and hydraulic components and systems; an awareness of their design features and methods of installation.

ii) Engineering Drawing

This course covers the scope and use of engineering drawing and provides the students with opportunity to develop fundamental skills and techniques in preparing engineering drawings; ability to solve drawing problems involving simple geometry; be familiar with standards (BS308:1984) and with orthographic projections, auxiliary views, dimensioning and pictorial representation of designs.

iii) Computer Aided Drafting

The basic techniques of drafting using microcomputer systems is taught to the students through lectures and practical involvement. The course sets out to give the student an appreciation of computer systems and an ability to produce simple geometric shapes on these.

On completion of this programme the students proceed from the
Industrial Centre to the first academic year of the Honours degree in mechanical engineering - BEng (Hons) - conducted by the Mechanical and Marine Engineering department. The current overall aims of the first year of the Engineering Design course are:

- '... to acquaint the student with the approach and techniques in engineering design, and the application of engineering knowledge in design development, analysis, detailing, and presentation of information.' [ibid., p 9.1]

The objectives of the first year course are partly enshrined in Finniston's statements on Engineering Applications 1 (EA1) [1980]. The course, as taught now, provides:

- Knowledge and experience in basic design tools and processes, selection of materials for engineering components, cost and process considerations... and the application of standard components in their (student's) design. In addition to EA1 practice... application of engineering principles...... and computer as a tool for the analysis of component design and production of .... drawings.' [Hong Kong, May 1988, p.9.1]

Key features of the existing course are:

The course, as it now stands, has key features that are stated in the course documentation. These are used in the teaching preparation and are also available to students for information. These features are:

- 15 one hour lectures;
- 15 one hour tutorials;
- 10 hours of formal training in Computer Aided Drafting;
- 20 hours of independent project and Design Studio work;
- Assignments are reviewed with individual or groups of students by lecturers (assignment are normally one major group project and two minor individual projects in year 1).
Key features of the same programme when modified to develop competence in technical design skills and social & interpersonal skills are:

On a general note:

material is developed for students stating clearly the objectives of the course, the course modules, method of instructions to develop and practice competencies, student expectations, assessment method and number of assignments assessed.

Both faculty and students have access to these documents to study and discuss openly.

Specifically in the Engineering Design subject:

- Same lecture programmes for specific subject matter with attention and emphasis drawn to skills competence development;

- Course is now divided into modules; study guides for each module (presenting student activities in the Design Studio/lecture room, home assignments with weekly commitments, topics for group discussions and presentations, references other than course texts, brief of term's major project;

- Descriptive type assignments including the use of free hand sketching;

- A major group project (preferably a community related one) is initiated at the start of the session with smaller groups working on specific areas of the major project - A beach Cleaner for Hong Kong : involves the students in site visits, interviews with community administrators and Government bodies, legal aspects of environmental protection, retrieving information on user and his social habits, and the technical aspects in the identification of the problem and arriving at suitable solutions;

- Assessment and review of work with equal students' participation;

- Student presentation of their combined and individual work to the rest of the course members, video taping presentation for feedback on performance;

- Specific tasks to be carried out on the microcomputer, particularly graphical work and some word-processing.

Development of details of the course as outlined above does not
necessarily require a total revamping of an existing curriculum. The enhancement is through the nature and organisation of assignments (or learning experiences) and the dual emphasis at all stages on subject content and competence. Aspects of student assessment also need to be addressed.

In assessing a traditional subject, the student's grasp of the subject matter is an important factor. In engineering design, assessing the level of competence, the student is required to discuss the social, political and environmental implications of a design assignment. In the first year the assessment is done by faculty and peers. In later stages, engineers from industry provide a 'dry run' for the maturing professional.

In a policy statement by the Engineering Council [SARTOR, 1985] titled 'Standards and Routes to Registration' (SARTOR), recommends the use of 'appropriate methods of examining and assessing students', having special regard to emphasis on the methods of problem solving using the latest technology available. It does not support the traditional '5 out of 8' closed book type of examinations for engineering design.

Black & Bradford [1975] conclude that in an open-ended team project, as most engineering design projects are - even in real life, it is difficult to assess an individual's ability. In their opinion only a continuous assessment process combined with project reports and oral presentation, to both peer groups and professionals, of the design work is academically acceptable.

The literature research does not suggest any one method of assessment for design work. There are, however, techniques that are suggested for the development of the main skills that are involved in design. These are shown below and are used in the proposed curriculum.
Educational strategies that are empirically demonstrated to be effective in the development of design skills are: (also refer to Figure 17, 18 and 19 on pages 168-170)

- Problem Solving and Engineering Judgement - Design Trees and Flow Charts; Case Studies; General Problem Solving Activities; Computer Simulation and Assisted Learning; Industrial Attachments; Sound Technical Science Base;

- Critical Thinking - Logical analysis of technical subject matter; Role playing by staff and students; Group discussions; Structured problems in Logic and Reasoning; Computer Aided Learning/Instructions; Inter-Departmental Seminars;

- Creativity - Brainstorming (both Osborn's Method and Trigger Sessions); Synectics; Morphological Synthesis; Decision Aids.

In view of the nature of the subject of Engineering Design and the evidence in the literature of the assessment techniques for design, the curriculum developed will concentrate on the strategies that foster the design skills rather than the assessment of students. The adult learning theories also support the view that the young adult needs only to be motivated and provided with a suitable environment for learning for him/her to achieve the course objectives (see this chapter, pages 157/158).

The sections developed below use the course quoted at the start of this section on The Curriculum (p. 175) and detailed in Appendix P.

This does not necessarily imply that the researcher agrees with what has been suggested in that course. The intention is rather to provide guidance by analogy to anyone embarking on such a mission - any of their own course content can be modified to increase students' professional competence.

The directives for this curriculum design are the three items detailed in section 2.2 (p. 162-171) of this chapter. Only the first year of the
course is considered in this instance since:

- objectives, which are the same for all years of the course, are stated at the start of the programme;

(Therefore, it is not necessary to repeat the objectives for each year of a course - although in practice the course documentation would include this for each year or stage of the course.)

- the first year is the foundation year from which the student can cultivate higher levels of proficiency in professional design skills during the later stages of the course;

(This requires emphasis at the freshman's stage of the undergraduate's educational process and, therefore, the first year is analysed in detail. The subsequent years are generally devoted to project work requiring higher levels of proficiency in the same skills.)

- a study of degree courses in the UK (Koroma, 1986; French, 1981; Cross, 1985) and in the Hong Kong Polytechnic shows a reasonable common first year course content in Engineering Design;

(The universal applicability of the research work and the developed model can be confirmed with this common first year curriculum)

- existing lecture programmes are used with added attention and emphasis on competence development; and

(This illustrates clearly that no re-vamping of existing course syllabuses is necessary - only emphasis on the competence aspects of skills identified and the learning experience environment that is to be provided are required. Therefore, only an example of the process of modification is necessary - the best one being the common first year Design course. Any curriculum worker anywhere can follow the example given and modify his/her programme accordingly.)

- a similar modification to include development of competence in the necessary skills can be carried out for any year of any course, keeping the major elements of an existing course.

(It follows from the previous statement that an existing syllabus need not be discarded - all current courses have some value in them. Faculty only need to address and incorporate in their curriculum the objectives and levels of proficiencies in the various skills that have
levels of proficiencies in the various skills that have been identified and clearly described. Taking the first year curricula as an example, the following years' can be modified in the same fashion, but with the higher levels of proficiency as the aim.)

- the second year of the course (see Appendix P) is essentially design practice and emphasises the application of knowledge gained in the other areas of the course. Specific systems are considered and CAD is applied to design of components and material data base is utilised. (see sections 1 to 5 of Year 2 syllabus in course documents, Appendix P)

(The emphasis in the advanced years is in the application of knowledge and this will be based on the general skills developed through the stimulus of the schema for the first year.)

The sample section of the first year syllabus that is developed below has four sections in the proposed documentation:

A. Course Introduction - containing course objectives, levels of proficiency expected of the student in the various design skills areas.

B. Course Text - list of text books and reference titles for the stage of the course.

C. Course Schedule and Outline - week blocks allocated to the various modules in the programme together with list of major topics covered during the week blocks.

D. Activities - detailed statements on actual activities to be carried out during specific week(s); levels of competence expected of students; target dates and schedules of work; assessment procedures.

The new curriculum also shows the relevant item in the adult learning characteristics that guided the design of the syllabus. The numbers correspond to the ones allocated to the list of characteristics developed by Knowles [1978] and shown on pages 157-159 earlier in this chapter.
The Revised curriculum

ENGINEERING DESIGN - BEng (Hons) - Year 1

A. Course Introduction:

A1. Objectives:

(The objectives stated below are drawn from the matrix model of skills and the propositions relating the various skills as proposed in Chapter 6, pages 140-153 and specified in this chapter, page 163, as a directive for curriculum design. This also caters to the adult learning characteristics - ALC - including all of the details given in the listing by Knowles [1978] shown on pages 157-159.)

The objectives of the course in Engineering Design are to enable the undergraduate to:

1. Use critical thinking skills to identify or recognise problems related to his field of study; collect and collate necessary data and information and make accurate engineering judgements.

2. Synthesise knowledge from his discipline, the sciences, arts, and humanities to observe, absorb and analyse environmental cues and employ appropriate problem solving strategies.

3. Be prepared to cope with constantly changing environment and technology and view previous experiences from new perspectives creatively.

4. Be prepared to master new technology and understand its impact on his profession and its utility.

5. Practice his profession within its framework of the code of ethics/practice.

A2. Levels of Proficiency:

(These levels relate to the directives listed on pages 163-166. From the adult learning characteristics, ALC, shown on pages 157-159, the relevant item reference numbers are given at the end of each skill level description.)

These are stated in the modules and activities of the first year course. In general, the levels of proficiency expected relate to the Level 1 in each of the skills areas as shown below:
Problem Solving and Engineering Judgement, Level 1: Demonstrate ability to formulate assumptions; identify implicit and explicit elements in order to apply simple and common principles; adopt appropriate methodologies to generate realistic solutions. [ALC - 1 b); 1 c); 2 b); 3 b); 4 a); and 4 c)]

Critical Thinking, Level 1: Demonstrate powers of observation, ability to generalise, conceive and state assumptions. [ALC - 1 c); 2 a); 3 a); 3 b); 3 c); 4 c]

Creativity (or Creative Thinking), Level 1: Ability to recognise a need and define the boundaries for design on his own. [ALC - 1; 2; 4; 1 a); 1 b); 1 c); 2 a); 2 b); 2 c); 3 c); 4 a); 4 c)]

Information Technology / Communications / Languages, Level 1: Demonstrate ability to receive and transmit technical information through oral, written, graphical and other media in a clear, accurate and neat format. (In this level emphasis is on the psychomotor skill, coordination, computational accuracy, use of computer graphics and development of self-confidence - in academic exercises.) [ALC - 1; 2; 3; 1 a); 1 c); 2 b); 2 c); 3 c); 2 d); 3 a); 3 b); 3 c]

Interpersonal and Social Skills are in a continuum and should be viewed as a maturing process in the student during the entire course. All levels are pertinent and significant at all stages of the course. These levels are:

Level 1: Identify personal values and their sources as they relate to a specific situation by self-analysis. (Emphasis here is on observing one's own feelings, thoughts, beliefs, ambitions and morals.)

Level 2: Demonstrate an understanding of the engineer's code of practice; exhibit autonomy in coursework.

Level 3: Ability to lead/follow and contribute in group projects; deal confidently with unpredictable, ambiguous and stressful situations

[For all three levels - ALC - 3; 3 a); 3 b); 3 c)]

B. Course Text

The text for this stage of the Design course is:

'The Engineering Design Process'
by B Hawkes & R Abinett, Pitman Publishing Limited, London

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Other references will be suggested during the course.

C. Course Schedule and Outline

Week 1-8 Design Module 1:

Introduction
Role of Engineering Design in industry
Outline of Design Process
Design Office Organisation & procedures

Week 9-16 Design Module 2:

Component Design Technology
Selection of materials for components
Fasteners, location and joining parts

Week 17-24 Design Module 3:

Standard components
Keys, gears, bearings, seals, couplings
Tolerances, limits and interchangeability

Week 25-30 Design Module 4:

Functional Elements
Linkages, mechanisms
Heat transfer, storage of energy

D. Activities

During the following weeks, tutorial sessions, seminar meetings, assignment assessments and Project meetings will be held as shown:

<table>
<thead>
<tr>
<th>Week No</th>
<th>Activity</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Group Project</td>
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Beach Cleaner for Hong Kong

Your only major project this year will be the above group project. The project involves all students on the course. You need to organise yourselves into groups to tackle various aspects of the project. [ALC - 1 b]

The initial step in to identify the problem. In order to start this you need to know the number and location of gazetted beaches in Hong Kong.

The relevant Government departments and publications are a good starting point. Establish current status of
beaches and the facilities for cleaning them (perhaps requires site visits and recording dimensions etc). [ALC - 4 a); 4 b); 4 c)]

Expectations: for the first stage of the project - ability to organise in groups; arrange visits to government and other organisations to retrieve and collect information; make arrangements for necessary official site visits; record relevant information in appropriate format; identify the problem and state this clearly in the form of specifications for a beach cleaner. Submit a preliminary report (Group Report #1) on your findings in week 10. [ALC - 1; 2; 3 b); 4 b)]

In terms of competencies we are addressing critical thinking by developing observational skills, ability to generalise in stating the problem clearly, conceiving and stating assumptions; problem solving by using the exercise as a case study in collecting sufficient and relevant information on the problem, making accurate judgements on the data in hand, and stating the technical parameters that are important to the problem (weight of dry and wet sand, details of waste materials found on beaches, availability of power sources at beaches etc); social skills by interacting with other members of the group in work sharing and discussions, decision making, 'meeting with general members of the society and officers in the government and other agencies.

Continuous Assessments of the progress of the project will be made during weeks 9, 14, 18, 22, 26 and 30. Should there be a need to meet at other times for any reason, this will be arranged on an ad hoc basis and when convenient for both the group and the staff member.

**Week No. Activity**

3 Assignment #1

Read Chapters 1, 2 & 3 of 'Design Methods: seeds for human futures' by JC Jones, Wiley, 1979.

Brief comments on the two chapters:

Chapter 1 - is a discussion on the definition of design and about what 'is' designing. Some questions are suggested for designers to ask and seek answers.

Chapter 2 - compares the traditional 'craft' approach to design with the modern views.
Chapter 3 - Four important questions are addressed in this chapter. Some tentative answers are supplied by the author. Read this chapter and discuss the contents amongst your colleagues.

Expectations: You will be expected to have read the three chapters carefully. Prepare an essay stating your views of the contents of the third chapter in 250 words and submit at the start of week 6.

[ALC - 1 b); 1 c); 3 a); 3 b); 3 c)]

In terms of competencies in problem solving, social and interpersonal relationships and critical thinking we are just establishing the vocabulary.

Week No Activity

6 Submission of Assignment #1

Submit your work to the subject lecturer or the Design Studio Technical Assistant.

Individual comments are made on the assignments. They are graded in terms of clarity, accuracy, neatness and originality of thought.

Week No Activity

8 Discussion of Assignment #1

This is in the form of a seminar led by the subject lecturer. After an introduction, assignments are returned.

Students are then invited to logically analyse the subject matter in an open seminar.

[ALC - 1; 1 a)]

Questions to be addressed are:

What is the definition of Design?

What is the difference (if any) between a craftsman and a designer?

What is the sequence of events in Design?

How does all this fit in with lectures on the role of design in industry and the design process?

[ALC - 3; 3 a); 3 b); 4 b); 4 c)]
Week No Activity

9 Group Project Meeting #2

Report to be presented by group leaders on the progress of project.

[ALC - 1 b); 1 c); 3]

Expectations: The meeting is primarily to provide a forum for students to interact in a formal environment; develop self-confidence and maturity; show leadership qualities and assume roles. It also provides opportunity to observe others in action and note the techniques employed in solving problems - these act as cues from the environment and need to be highlighted during the session.

[ALC - 1; 2; 3]

Targets set for next meeting - week 14; systems in design to be decided and further grouping carried out if necessary for the technical solution to problems; project work interacts with course work started in week 3 and assessed in week 8 adding meaning to lectures on definitions of Design and the process.

Week No Activity

10 Assignment #2

Read Chapters 1 & 2 of the course text, 'The Engineering Design Process' by B Hawkes and R Abinett, Pitman, 1984.

Solve problem 1.2 on page 31. Prepare necessary sketches and details to present to the class in week 15.

Brief comments on the chapters:

Chapter 1 - shows a systematic approach to the solution of design problems. Note the extensive use of free-hand sketching in the designs; the accurate proportions used in these to represent clearly the overall sizes; and the range of problems illustrating the design process in action.

Chapter 2 - shows the organisation, planning and evolution of a design; company and design office hierarchy and structure; some examples of charts used in design planning.

Expectations: You will be expected to present your solution to the class. Bear in mind the following points
that relate to technical communication and will be assessed during your presentation -

a) Know exactly what you want to convey.

b) Remember who you are addressing.

c) Select the most appropriate method to communicate your ideas and views.

[ALC - 1; 1 a); 2 b); 2 c); 3; 4 b) 4 c)]

In terms of competencies, your skills in graphical and oral communications are developed; your mastery of the technical content of the subject matter will have an influence in the design alternatives and synthesis.

The assessment, at this stage, stresses the acquisition of good work habits (attention to accuracy, neatness, speed, legibility, use of computers, use of engineering drafting instruments, and presentation of information).

Week No. Activity

14 Group Project Meeting #3

Read 'Problem Solving through Creative Analysis' by Tudor Rickard, Gower Press, 1982 Edition.

Chapters 1, 2 and 3 are important;

Chapter 4 Section 4.3 and Chapter 5 are relevant to the project;

Chapter 8 Sections 8.3, 8.4, and 8.5 are useful examples;

Chapter 12 Section 12.2 and 12.5 are interesting.

Study Chapter 12 Section 12.5 carefully. Relate Rick Johnson's five critical steps to the project in hand and devise similar critical stages for the Beach Cleaner project.

Expectations: You are expected to be prepared for a brainstorming session at the next meeting - week 18. The aims here are to introduce techniques of problem solving that are not traditional in core engineering subjects where correct answers exist for all paper problems. You should read the text suggested and familiarise yourself with the ground rules for these techniques.

[ALC - 1 a); 1 c); 2 c); 2 d); 3 c); 4 a); 4 b); 4 c)]
Week No Activity

18  Group Project Meeting #4

Group sessions in idea generation for Beach Cleaner. Osborn type brainstorming techniques introduced to the small groups. Groups prepare separately for exercise in brainstorming by tackling simpler engineering component, for example, a car jack. This is broken down to functions of lifting, holding and lowering a vehicle. A morphology exercise (which is linked to Osborn brainstorming technique) can now be carried out and methods by which each function can be achieved are drawn up (the dimensions).

Expectations: All students are expected to participate during the training sessions in these techniques. Once you understand the strength and advantages of these techniques you will handle future design problems logically and with more confidence - particularly open-ended problems with no one correct answer.

[ALC - 1; 1 a); 1 b); 1 c); 2 c); 4 a); 4 b); 4 c)]

Week No Activity

19 & 20  Individual Presentation of Assignment #2

Each student will present to the rest of the class his solution. Be ready to answer questions on the design and related technical subject area.

Expectations and assessment details are given in the notes on week number 10.

[ALC - 1; 1 a); 2 b); 2 c); 3; 4 b); 4 c)]

Week No Activity

23  Assignment #3

Write a short essay on the social and political aspects of the design and construction of the Daya Bay Nuclear Plant. Essay should be about 500 words long.

Expectations: The purpose of this exercise is to introduce you to the study of power relationships in public affairs that affect the designer. You will learn about the way politicians communicate and exercise both authority and power. You will learn to identify the explicit and the implicit elements in statements.
You are expected to read extensively on the subject both in the technical literature and in the public media. Discuss this with your colleagues, friends and family. Consider the situation in a thoughtful way and identify your personal values and their source and relate these to the question of Daya Bay as a power source for the region. Observe your own feelings, thoughts, beliefs and morals. Record these and discuss in your essay.

[ALC - 1 b); 1 c); 2 b); 3 b); 3 c); 4 b)]

The assessment in this exercise is your proficiency in critical thinking and in the social skills. More value is placed in your own assessment of the problem and the logic and reasoning used in arriving at your conclusions.

**Week No Activity**

26 & 27 Discussion on Assignment #3

This is a group discussion session. You are expected to relate statements made by non-technical persons that sound very authoritative and examine these to establish validity and make judgements based on your own values.

Expectations: These are given in the notes for week 23.

[ALC - 1 b); 1 c); 2 b); 3 b); 3 c); 4 b)]

Assessment in this is based on your ability to think critically and come to conclusions based on evidence that is available to you.

**Week No Activity**

28 & 29 Group Project Presentation

The final design is presented to a mixed audience of students, faculty and specially invited guests from other departments. Two session are held - one for the assessment of individuals in each of the groups where only one student and the lecturer meet and discuss the project as a whole and the individual's part in it and the second, a more formal one, for all students, faculty and invited guests.

Expectations: Exhibit ability to prepare and present a comprehensive design proposal to a peer group audience in a formal atmosphere; show full understanding of technical matter related to design and indicate all assumptions made; make use of suitable audio-visual aids
to make presentation clear and logical; deal confidently with unpredictable questions from the audience; submit comprehensive report giving all salient facts and details; take an active part in the proceedings if you are a member of the audience.

[ALC - 1; 1 a); 1 b); 1 c); 2 d); 3; 4]

Week No Activity

30 Concluding Session

This session is the last week in the academic year and student feedback is sought on problem areas and where improvements or adjustments can be made in the general running of the course and the project in particular.

Week No Activity

Some of the weeks that are not listed above (weeks 1, 4, 5, 7, 11, 12, 13, 15, 16, 17, 21, 22, 24, and 25) are used in the formal lecture programme to cover topics listed in the course syllabus [Hong Kong, 1988].

These lectures will include the topics listed in the course curriculum (Appendix P) -
- Introduction Lecture
- Component Design Technology
- Functional Elements
- Common Engineering Components
- Computer Aided Drafting and Design

The general aim is to cultivate a wide technical vocabulary and familiarity with components and their functions in an engineering system. The application and use of computers as a tool in all stages of design work is expected.

(The details of these topics and the teaching methods are given in the course documents, Appendix P)
Chapter 8
Conclusions and Recommendations

Overview

Recent reports on the education of engineers [Finniston, 1980; EC, 1984; IMechE, 1986] have emphasised the inclusion of a large component of design experience in the engineering curriculum. None of these reports, however, address the question of objectives and learning activities that need to be included in a curriculum to provide this design experience.

A general literature search on engineering and design education and published reviews of various engineering courses [Koroma, 1986; also see Chapters 2 and 3] also indicated that there was an urgent need to provide guidelines or a model for the development of a design curriculum.

Added to this was the author's personal experience of teaching design for over ten years that not only supported the urgency of the situation but also germinated the concept of a model curriculum for design education.

The catalyst that finally triggered the author into formally working on this theme was a curriculum that was proposed and accepted for an honours degree programme in mechanical engineering. It was clear then that educators in engineering (and particularly engineering design) were working as rank amateurs with only a cursory knowledge of principles of education and learning theories. This was a serious handicap in the development of a meaningful curriculum for engineering design education.

The primary purpose of this research was, therefore, to produce a curriculum development model for engineering design education.

The study involved three major stages:-

Firstly, the results of a literature research, survey of practicing professional engineers and an input from undergraduates produced a paradigm
of a practicing professional engineer (Chapters 2, 3, 4 & 5).

Secondly, the concatenation of the skills and attributes, their interactions, the identification of suitable educational strategies, and the theoretical underpinnings of curricula directed the metamorphosis of the curriculum model (Chapters 6 & 7).

Thirdly, a sample curriculum was generated employing the already defined objectives and the proficiency levels expected in the learner. Identified educational strategies were allocated in the curriculum where appropriate (Chapter 7).

In this chapter, the conclusions are presented in light of these three stages of this research.

Conclusions

General Engineering Education

The literature survey shows that engineering education is increasingly accepted as a sound general education not only for the profession but also for entry into different career paths, particularly in the United States (see Chapter 2, p.13). There is, however, a general air of pessimism in respect of the preparation of engineers for a career in the profession (Chapter 2 p. 19-20) [also Fielden, 1963; Wilde, 1983; Whittley, 1984].

It is clear that where there is a close linkage of the education of the engineer and the national ambitions, the manufacturing industry is healthy and prosperous [McCormick, 1985]. However, it was the Japanese view of the freshly graduated engineer - 'degree is no proof of his ability' - [Hutton, 1986; Lorriman, 1986; also see Chapter 2, p. 16] and the issue of design education being addressed by the country's top executive in the UK [Sheldon, 1984; Chapter 2, p.18] that made this research immediately more
meaningful and necessary. Engineering design had, in a sense, "arrived".

**Engineering Design Education**

Right at the onset, the pinning down of a definition of *design* proved to be a complex task. The word has many prefixes. Each has its own message, significance and substance. The definitions suggested by two respected sources [SEED, 1985; Harrisburger, 1976] that were basically very similar (see p 6 and 7) were considered reasonably descriptive of an engineering designer's tasks.

The assertion that design was the raison d'etre of engineering is supported in the general literature [Ashford, 1968; Kimber, 1972; Caulkin, 1979; Finnistston, 1980; Smith, 1986] and more emphatically in journal articles authored by industrialists [Wilde, 1983; Carey, 1979; Fletcher, 1986; Penny, 1981; Roith, 1986]. The accent in these publications is, with rare exceptions, more on the 'product' than in the 'process' of design. While this is understandable, academics need to be aware of this phenomenon and emphasise the true learning experiences in a curriculum for design education.

Professional bodies have also added weight to this assertion having recently issued directives to educational institution to integrate design in degree courses in engineering [EC, 1984; IMechE, 1986; SERC, 1985]. Academics in engineering schools are currently making efforts to infuse and blend design into their engineering curricula [SEED, 1985 & 1988].

Academics, however, do not agree on 'what' and 'how' to teach and have not generally addressed the important issue of 'how' students learn engineering design [Chapter 2, p.30; also SEED, 1985]. Some researchers argue that methods of systematic design evolve as a designer's personal methodology rather than the application of published techniques [Tebay,
This implies that design, in terms of methodology, cannot be taught. Others focus on the importance and the necessity of faculty influence and guidance in the undergraduates learning process in engineering design [Chapter 3, p.48; also Marton, Chapter 9, 1984].

The activity of design is not limited to the methodology dimension alone. Accepting this, the education of an individual to attain some degree of engineering design competence is viewed in two dimensions - the cognitive competence and the social/identity of the professional.

Many approaches in teaching design are evident in the surveys of engineering courses reported in the literature. In most of these, familiar design phrases (e.g. Problem Solving, Creativity, Critical Thinking, Engineering Judgement) are stated with no clear definitions or suitable learning strategies suggested.

It is hoped that the model developed in this research work goes some way in constructing a comprehensive guide for engineering design curriculum developers.

Survey and Concept Mapping

The professional survey carried out in Hong Kong proved to be very successful in the first three stages. The response rate was over 80% for the third stage. This verified the preference for a postal survey over other methods of data collection.

However, an effort (Delphi-type survey) to gather more conclusive data and a consensus of opinion on what an engineering designer would and would not be doing in five years time, resulted in less than 5% response and had to be abandoned. This was disappointing, particularly as the earlier responses had been excellent. One reason for this low response could be
that industry in Hong Kong (and perhaps elsewhere also) is in the process of rapid change and predictions under these circumstances are not always easy or even possible.

Nevertheless, the survey and the non-parametric analysis of the data showed that there is a strong correlation between what the practicing engineers found useful in their daily work and the subjects nominated by them for a degree programme.

Concept mapping technique employed in this work also proved to be an effective tool in determining the student's perception of a professional engineer. By the third attempt at this activity, most student's exhibited a high level of proficiency.

In concept mapping their views of a professional engineer, the students tended to develop the concepts rather like their maps of engineering components - function first and then the operational skills requirements. The first map of the professional was taken as the final one in the study and analysis of their perceived views. This ensured that the views expressed were voluntary and not influenced or directed by the researcher.

The maps suggested that the beginning professional held a broad and all-inclusive view of the practicing engineer. There were some exceptionally well developed maps and others which were simple (see Appendix M for samples).

The students identified Information Technology, Languages and International Trade and Relations as additional facets (to those found in the literature) that are desirable in the professional engineer. These are broad terms and incorporate many individual items of a similar nature under each title (see Chapter 5, Section 3.2).
Many students commented after the exercises that concept mapping could be a useful tool for them in the understanding of other subject areas. The use of this tool as a learning strategy at the tertiary level of education should be further investigated and encouraged.

It has its weaknesses and drawbacks when applied in engineering. For example, its limitations, as it is applied today, is in the use of only 'words' to develop concepts. Engineering concepts, particularly in terms of engineering design, involve complexities and interaction between components and systems of a level that description by words alone becomes tedious and elaborate, if not impossible.

Incorporating pictorial representations or free-hand sketching in concept maps relating to engineering would broaden the scope of application of this tool in education and learning. This is particularly suitable for mechanical engineering students who constantly deal with energy conversion, motion and transfer of power from one point to another. This is an area that needs to be researched further.

Design Trees, a technique sometimes used in preliminary design work and similar to concept mapping in its initial stages of development, does not appear in the majority of design syllabuses examined in this exercise.

A combination of the two techniques - Concept Mapping and Design Trees - could form an excellent tool for engineering design in the academic world and for the practicing professional. This also needs to be studied and researched further.

The Skills Matrix Model

The skills and attributes identified for effective engineering design practice were Problem Solving, Critical Thinking, Creativity, Engineering
Judgement, Ethics, Integrity, Autonomy, Leadership, Self-Confidence, Self-Efficacy and supporting skills in Communications, Languages and Information Technology. Core Knowledge Competence in the discipline was considered essential for the engineering designer.

The first model was drafted from the literature research on professional education and an input from the above list. In identifying job descriptions and details, the postal questionnaires method was chosen as a suitable one (see Figure 8, p. 56). The elements in the questionnaires were guided by the current state of job opportunities in Hong Kong. This was achieved through the study of local media (specially the newspaper) advertisements for engineers (see Appendix E) and the Hong Kong Polytechnic Student Affairs Unit's data on graduate employment (see Appendix F). This proved to be the right approach - as the response to the three questionnaire stages clearly showed (see Chapter 5, p. 71-86).

This was possible and relatively simple since Hong Kong is a compact territory with excellent and inexpensive communications infrastructure. Such an exercise in a larger nation will be more complex and may need to be done initially on a regional basis rather than a national exercise.

The skills involved in the effective practice of engineering design, however, is essentially common to all regions - as indicated by the literature search [Harrisburger, 1976; SEED, 1985 & 1988]. Employers are also generally multinational organisations with operations in many parts of the world. Therefore, a model of these skills developed in one region is basically applicable in any other part of the world - in the generation of a curriculum for design education.

While the first model described the necessary skills for the designer comprehensively, it was not suitable for curriculum design - there were too
many interlinking propositions and the specific directives for an engineering design curriculum could not be identified clearly. The model was refined and revised (see Chapter 6, p. 145-153).

The refinement of this model was carried out by collecting opinions and views of practicing engineers and academics involved in the teaching of design. The response from practicing engineers was, again, disappointing. Academics, however, were more forthcoming with comments and criticisms. The two types of responses are, perhaps, indicative of the opposing views held - the academic's pedagogical view of the teaching of this subject as a 'process' against the pragmatic 'product' approach of the practitioners.

The final stages of refining the model was, therefore, guided to a large extent by those most involved in the teaching of the subject. This is acceptable since the original model was constructed with data almost entirely from practicing engineers. This fine tuning by academics and a few others enabled directives and propositions to be deduced from the revised model.

The revised model turned out to be simple but elegant (p. 150). The core of the model is the technical competence area. The characteristics in this core enhance the creative skills domain of the engineer. All these operate within the interpersonal and social skills domain which in turn is influenced by the environment in which the engineer operates.

The propositions were narrowed down from the original fourteen to six to reflect the interactions of elements in the new model. This enabled the formulation of directives for curriculum design in the form of objectives for a design course. The propositions are universal and can be used by any engineering curriculum developer (p. 152-153).
The strength of the model is in the extensive theoretical and empirical support - in the literature survey and from the input of the practicing professional engineers.

The propositions that were derived from the revised model (see p. 152) themselves are a means for its interpretation and further analysis. These were generated to direct the production of a model curriculum.

Model Curriculum

It is evident that curriculum designing is both an art and science with its own store of knowledge, theories and standards (see Chapter 7).

Planning a curriculum to develop design skills and attributes necessitated the study of cognitive learning processes (Chapter 3, p. 42). The literature survey indicated quite clearly that bulk of the research work in the cognitive learning processes is either to do with adolescents in North America or animals.

In the absence of such work specifically related to engineering, adult learning theories were considered for directives in defining objectives for curricula in engineering design (Chapter 7, p. 157-158).

All through the curriculum design process, relevant adult learning characteristics and their the implications for adult learning (combined with course objectives and levels of proficiency) form the basis for decisions and are quoted wherever necessary (Chapter 7, p. 183).

The curriculum example is constructed to develop competencies in all the skills identified and is supported by the theoretical underpinnings of curricula. Techniques that are theoretically and empirically supported in fostering these skills are the basis for learning experiences that are suggested.

The curriculum also views the learner as an active partner in the
teaching/learning situation. While the proposed design curriculum is not totally learner-centred, it has moved from the traditional teacher-centred courses that are all too common, even in 1988. A balance is maintained where the beginner is guided rather than taught. This shift of balance is an important and necessary move, especially in an institution in a developing nation - the student has first-hand experience of the 'design' world and not a pre-determined 'problem-solution' exercise conducive to rote-learning. The new curriculum exposes the student constantly to the realities of professional engineering practice.

Applications in Other Environments

The study is an effort at synthesising the needs of the profession, the curricula demands and the needs of the learner in an engineering context. These are essentially related to the needs of Hong Kong. These demands are bound to vary from time to time and in different institutions and locations.

The method and model proposed in this research are offered as a guide to institutions and as a criterion for those working in the field. It is one way an engineering course can be better formulated and hence prepare the beginning professional for an effective and long career in engineering.

The unique feature of the model is that current course content need not be altered. In applying the model to any syllabus in Engineering Design, only the management and learning strategies in the assignments need to be revised.

The model curriculum is an example of the application of the findings of this research work in the development of details within a design syllabus. The model course curriculum is cross referenced to illustrate the
procedure in detail.

**Recommendations**

The needs of the learner, particularly the adult learner, as indicated by the literature is for more independence in selection, planning, and execution of learning exercises. The adult learner needs the opportunity to identify the competency requirements of his occupational and social roles. It is clear the adult learner needs to be consulted in curriculum design.

The future curriculum may well be drawn up as a joint exercise between the learner and the institution or a faculty member - a kind of Teaching and Learning Contract (TALC). As a learner progresses through a course, TALC may be revised, redrafted or restructured to suit the new needs or circumstances.

In engineering design education, such a schema (as TALC) is highly desirable - a formal curriculum is less valuable than finding out what the learner wants to learn. This is particularly appropriate for the senior years of an undergraduate course.

The work carried out in this research has thrown open many areas that need to be pursued and researched further. Learning process in engineering, particularly the concept of problem solving, is an area that is being addressed vigorously now.

The other skills identified are also subjects of on-going research by psychologists, but not by engineers. Perhaps a joint research with the two disciplines involved would be mutually beneficial.

The professional skills matrix model proposed could itself be studied further. The interlinking propositions are, in each case, an area ready to be formulated into hypothesis for research.

Finally, the time has arrived for all tertiary engineering schools
to build in competency criteria into their curricula as an equal partner with technical content in all subject areas.

In engineering design schemes, competency must take priority over technical content. To achieve this, the following recommendations are made for engineering faculty to review their design curriculum.

1. Identify existing curricula design assumptions.

2. Identify the instructional strategies employed.

3. Determine whether professional competence is addressed and to what extent.

4. In engineering design syllabuses, maintain current course scheme, in terms of technical content, if consider suitable.

5. Use the skills matrix model and subsequent derived objectives and proficiency levels for these skills as given in this research to modify existing learning experiences and strategies used (if any) in your assignments.

6. Introduce non-technical aspects of public utilities systems (power generation, transport, defense etc) to develop social and interpersonal skills within an engineering environment.

7. Increase awareness and interest in all staff in the new course objectives, enlist the support of colleagues and maintain this contact with the curriculum.

8. If engineering education is to meet the projected demands of the future, the institutions must provide the necessary resources and positively encourage the development of meaningful professional curricula based on theoretical and empirical underpinnings of the necessary skills and attributes.

9. It is recommended that any research in engineering curriculum design should, when possible, emerge from a sound educational theory base.

10. Potential users of this model are directed to study the adult learning characteristics and the implications on adult learning prior to commencing the design of the curriculum.
11. While this study was based on the education of a mechanical engineering undergraduate, it is more than likely that the model can be applied to curriculum design in other engineering areas, such as Electrical, Production and Manufacturing, Electronic, Civil, and Structural Engineering.

12. With slight modifications to the skills matrix model and the derived propositions, this work could form the basis for curriculum design in other disciplines such as medicine, architecture, law and business studies. Such applications need to be researched and the proposed model re-structured.
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APPENDIX A

List of Participating Organisations
APPENDIX A

List of Participating Organisations

The following 14 organisations confirmed their participation in writing at the first stage of the survey (in alphabetical order)

1. AS Watsons & Co
2. Associated Engineering Co
3. Durable Electrical & Metal Co
4. Electrical & Mechanical Services, Hong Kong Government
5. Hanimex (HK) Ltd
6. Hong Kong Productivity Centre
7. Hong Kong Telephone Co
8. Jebson & Co
9. Kowloon Motor Bus Co
10. Outboard Marine Asia Ltd
11. Parsons Brinkerhof Asia Ltd
12. Royden Electrical Engineering Co
13. Sonca Industries Ltd
14. Support from Hong Kong Federation of Industries (see Appendix I)

In the next stage the following joined the above organisations:

* Analogue Technical Agencies
* Electronic Industries Ltd
Garden Co
* General Electric Co
* Hong Kong Aircraft Engineering Co
* Hong Kong and China Gas Co
* Hong Kong United Dockyard Ltd
Hunters Leatherware Ltd
* Jardine Engineering Corp Ltd
Lam Soon (HK) Ltd
Levi Strauss (Far East) Ltd
MC Packaging (HK) Ltd
Miniscribe Ltd
* Motorola Semiconductors Ltd
* Siliconix (HK) Ltd
Unison Knitting Factory Ltd

Organisations that were considered suitable for this stage and who could provide suitable information for the third stage of the survey.
APPENDIX B

Stage I Questionnaire Sample
Appendix B

HONG KONG POLYTECHNIC

Mechanical & Marine Engineering Department

Industrial Survey - Organisations in Hong Kong involved in Engineering Design / Modification work

An effort is being made to establish the education and training requirements for Design Engineers for the Industries of Hong Kong. The first stage is to identify organisations that carry out work which can be broadly classified as Design - primarily in the Mechanical Engineering field.

Your organisation may be one of these. We would like to know more about your requirements so that we can produce a suitable graduate for your needs.

Please complete the questionnaire attached to this letter and return it:

KK Chandran
MME Department
Polytechnic
Hung Hom, Kowloon

You may call K-638344 Ext 768/761 for any further information.

The survey is purely for academic purposes and strictly confidential. All information will be destroyed once statistics are evolved out of these.

Your kind cooperation will help to ensure that the Polytechnic, and in particular the Mechanical & Marine Engineering Department, produces the kind of graduate that you require.

Thank you.
Design Engineer - Survey of Hong Kong Industries

December 1984

1. Name of Organisation

2. Address and Telephone Number (Please give name of person for contact & Tel No.)

3. Total number of employees

4. Type of industry

   Aircraft __ 1
   Chemical/plastics __ 2
   Electrical equipment __ 3
   Electronic Equipment __ 4
   Land vehicles (except railways) __ 5
   Mechanical equipment __ 6
   Metal production __ 7
   Oil related __ 8
   Reclamation/construction __ 9
   Rail transport __ 10
   Ship & Marine related __ 11
   Wood & wood products __ 12

5. Others - please specify __

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6. If your organisation is engaged in manufacture, process production or maintenance & repair which of the following most closely describes the work of your firm?

Cross ONE number only

Supply imported equipment and service them 1
Mass production - Assemble imported components 2
Design and manufacture in Hong Kong 3
Modify equipment to customer needs & service 4
Production of standard components used in wide range of design/equipment 5
Process production - chemicals 6
Continuous flow production of gases, liquids, and crystalline substances 7
Fabrication of large equipment 8
Repair 9
Production of units to customer's requirements 10
Not any of the above 11

7. If none of the above describes you firm's work state briefly the type:

________________________________________________________________________
________________________________________________________________________

8. Does your organisation have a Design/Development Group?, YES/NO

9. Would your organisation be prepared to take part in a survey of Design Engineers in industry in Hong Kong? (Such a survey would take less than 2 hours of a senior member of your firm involved in this area)

YES/NO

10. Any comments/suggestions:

Thank you for your kind cooperation. We look forward to meeting you for more detailed analysis of the role of Design Engineers.
KKC/DEC 1984 (HKPolytechnic)
APPENDIX C

Stage 2 Questionnaire Sample
Appendix C

1. Introduction

1.1 Hong Kong has been going through a period of rapid development in the manufacturing sector - both engineering and others. While the importance of engineers in such a situation is readily understood, very little information is available on their numbers, types, training and educational background, functions and roles in employment.

1.2 A research project has been undertaken in order to fill this gap. A survey is to be carried out of relevant industries in Hong Kong to discover the type of careers engineers have progressed through. Their views on the relevance or otherwise of their academic background will be sought. The basic intention is to identify engineers working in industry and other organisations in Design or Development areas and assess their views on the situation now and, say, 10 years hence. It is hoped that such a survey would provide useful information for the planning of education and training of future professional engineers in Hong Kong. A further benefit would be to make manpower planning more efficient and realistic. It would also point out to the outside world (the potential investors) the availability of such professional skills in Hong Kong.

1.3 For the purposes of this survey a professional engineer is one who satisfies one or more of the following conditions:
   i) Has a Degree from a recognised institution and is now in relevant employment;
   ii) Is a corporate Member of the Hong Kong Institution of Engineers or equivalent body;
   iii) Has a Higher Diploma from the Hong Kong Polytechnic and/or the Associateship of HK Polytechnic.

2. Method of Survey

2.1 Initially a pilot survey is to be carried out to test the reaction and response to such an exercise. The companies selected are the ones which have shown interest in taking part in the practical training of undergraduates from the Polytechnic Degree courses. Appendix A shows a sample questionnaire.

2.3 A more comprehensive survey will be carried out later which will include past graduates of the three tertiary institutions in Hong Kong who are either working involved in Engineering Design or Development now. Mailing list will be compiled with the help of the three institutions and the HKIE. It may be necessary to ask overseas professional bodies for a list of their members who are employed in Hong Kong. It is conceivable that some names will appear in more than one list - particularly Chinese names. Effort will be made to eliminate duplication and at worst minimise it.

2.4 It is hoped that the three educational institutions, the professional bodies and the Government bodies will co-operate in compiling this mailing list.
2.5 Since the bulk of the analysis is qualitative, the time involved is likely to be significant—6 to 12 months. There will, however, be some quantitative analysis carried out and this will be done on the computing facilities available at the Polytechnic.

2.6 Please complete the enclosed questionnaire and send it to

KK Chandran  
MME Department  
Polytechnic  
Hung Hom, Kowloon  
-------------------  
(Tel: 2638344 x768/761)

2.7 Thank you for your kind cooperation in this project.
Appendix A

Part I

Organization details:

1. Name of organization and address:

2. Name of person completing the form:
   Mr/Dr/Ms
   Position:

3. Telephone number:

4. Total number of employees:

5. Number of Graduates (all disciplines) employed:

6. Total number of professional engineers - (ref section 1.3 of Introduction, page 1):

7. How many of your professional engineers are graduates of:
   a) Hong Kong University
   b) Chinese University (HK)
   c) Hong Kong Polytechnic (Higher Diploma & Associateship ONLY)

8. How many of your professional engineers are graduates of:
   a) a UK university
   b) a US university
   c) Australian University
   d) a University in China
   e) other countries
7. How many of your professional engineers are Corporate members of any of the following Institutions?

a) Hong Kong Institution of Engineers
b) Any professional Institution in UK (eg: IMechE, RAeS, IEE, ICE)
c) Australian or New Zealand Institutions
d) Other (please state country)

10. Number of professional engineers employed in Design/development/research/modification

i) number involved in design
ii) number involved in development
iii) number involved in research
iv) number involved in modification

11. If none of the above describes the work carried out in your organisation state briefly work you do and consider relevant to areas in Question 10, i) to iv): (If more than one area is identified please state them separately and give number employed in each area)

<table>
<thead>
<tr>
<th>AREA</th>
<th>No of Professional Engineers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Please state number employed in each area

12. How long has your Design function (or related area as per question 10) been in existence in Hong Kong:

(Please tick appropriate one)

- less than one year
- between 1 and 5 years
- between 5 and 10 years
- between 10 and 15 years
- over 15 years

13. Does your organisation expect (or plan), over the next ten years, the Design related areas to

a) expand
b) be reduced
or c) remain as it is now?

14. Do your professional engineers have access to computers of any kind?

YES/NO

15. Are the computers used:

- mainframe units supporting terminals
- microcomputers
- both mainframe & microcomputers

226
16. Does your organisation follow any of the following standards in the Design process? (please tick appropriate one(s))

- BS
- DIN
- JIS
- ISO
- American
- Australian
- other(s)

Please state type(s)

17. How many of your professional engineers are working for higher degrees/qualifications?

18. Please list below names of professional engineers in your organisation whom you would nominate for a detailed survey:

<table>
<thead>
<tr>
<th>NAME</th>
<th>TEL No.</th>
<th>ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

19. Any comments:

Thank you very much for your kind cooperation in this research project.
APPENDIX D

Stage 3 Questionnaire Sample
Hong Kong Industries - Design Engineers

Survey - May 1985

1. Name of Employer: ____________________________

2. a) Name of person completing form: ____________________________
   b) Age next birthday
      Below 25 [ ]
      26 - 35 [ ]
      36 - 45 [ ]
      Over 46 [ ]

3. Title/Position in organisation: ____________________________

4. How long have you been with this organisation:
   less than 2 years
   between 2 - 5 years
   over 5 years

5. Academic qualifications:
   Institution exam completed ____________________________
   University first Degree ____________________________
   Technician Diploma ____________________________
   Higher Diploma ____________________________
   Associateship ____________________________
   Masters Degree ____________________________
   PhD ____________________________

(*) Local = HKU/CUHK/HKP; UK = United Kingdom; NA = North America)
6. Professional institutions - memberships:

<table>
<thead>
<tr>
<th>Institution</th>
<th>Corporate</th>
<th>non-corporate</th>
<th>nil</th>
</tr>
</thead>
<tbody>
<tr>
<td>HKIE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A UK Institution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A USA Institution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australian Institution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Zealand Institution</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>others (state titles)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. What was the major area of your engineering education?
(Tick only ONE, or exceptionally TWO)

- Mechanical
- Electrical
- Chemical
- Civil
- Structural
- Marine
- Aeronautical
- Production
- Industrial
- others (Please state)

8. What type of work did you do in your first full time job?

- Engineering Training
- Apprenticeship
- Sales/Marketing
- Administration (Tech)
- Administration (non Tech)
- Teaching
- Design
- Research & Development
- Production
- Maintenance
- Work Study/D.R.
- Testing/Inspection
- others (Please state)
9. **PLEASE READ INSTRUCTIONS CAREFULLY**

Rate the following subjects studied at first degree level:

- i) In the past five working days how many times have you used this subject?
- ii) If you have not studied this subject, mark here
- iii) How useful this subject in your work? Tick appropriate box for each subject.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>very useful</th>
<th>useful</th>
<th>not useful</th>
<th>not studied</th>
<th>never</th>
<th>once only</th>
<th>more than once</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Drawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Properties &amp; Strength of Materials</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanics of Machines</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamics of Solids/Vibrations</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Automatic Control/Instrumentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrical Technology</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Electronics</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Computing Studies/Programming</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering Design</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Work</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Report Writing</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Industrial Management</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Work Study</td>
<td></td>
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<td></td>
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<tr>
<td>Production Engineering</td>
<td></td>
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<td></td>
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<tr>
<td>Fluid Mechanics</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Thermodynamics</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Aeronautics</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
10. How long did you stay in your first job?

- less than 1 year
- between 1 & 3 years
- over 3 years
- still there

11. Which of the following would you consider the nearest description of the present work you perform?

- Mainly Sales and Marketing
- Consulting and Design
- Mainly Administration
- Construction
- Manufacture
- Finance
- Operation/Maintenance
- Education/Training

12. Considering the main tasks you perform in your present job, which subject areas(s) in your engineering education do you feel was (were) neglected or not treated in sufficient depth?

If list below does not include subject(s), please state

- Engineering Design
- Management
- Computing
- Report writing
- Project work
- Others

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13. Since completing full time education have you attended any part-time (40 hrs duration) or short course (1 week)? Please tick appropriate one.

YES/NO

14. If you were to design a first degree course list the 10 important skills given in order of priority.

1. ____________
2. ____________
3. ____________
4. ____________
5. ____________
6. ____________
7. ____________
8. ____________
9. ____________
10. ____________

15. Do you think Engineering Design should be included in all undergraduate Engineering courses.

YES/NO

16. Do you use a computer of any sort for any aspect of work?

YES/NO

17. Do you have any access to Computer Aided design/Manufacture?

YES/NO

18. Would you have liked more elective/optional subjects in your first degree course?

YES/NO
19. In the design of an Engineering first Degree course how would you rank the following non-technical subjects?

(Rank them from 1 to 6. Do not use equal ranking.)

English  
Economics/Accountancy  
Management  
Engineer in Society  
Mandarin  
Other foreign Languages

20. In your opinion, should Engineering Design subject be made compulsory for all first degree students?

YES/NO

21. Do you expect the work you are currently doing to be done entirely using a computer, say, in

5 years?  
10 years?  
never?

22. In your daily work do you have to refer to:

i) International Standards?
ii) Company Standards?
iii) Manufacturer's Catalogues?
iv) Set your own standards?

23. Are you ever involved in drawing up or interpreting specifications for design of components/systems?

YES/NO
24. Since graduating which of the following areas have you been involved in: (tick all appropriate ones)

   i) Preliminary Design
   ii) Detail Design
   iii) Strength Analysis
   iv) Checking of Designs
   v) Production/Manufacture
   vi) Costing/Finance
   vii) Sales/Marketing
   viii) Management
   ix) Research & Development
   x) Maintenance/Inspection

other (Please state)

25. What type of training programme/course would you like to attend to improve your work skill/performance?

Please state briefly:

******************************************************************************

Please go back and CHECK that you have answered all questions as accurately as you can. THANKS.
Please post to:

KK Chandran
MME Department
Hong Kong Polytechnic
Hung Hom, KOWLOON

Should you have any reason to contact me regarding this exercise please call:

K-638344 Ext. 768/761/790

KKC/May 1985
APPENDIX E

Classified Advertisements for Engineers in Hong Kong
Influence of Advertisements for Engineers in Hong Kong on the construction of Survey Questionnaires

Advertisements were taken at random from the local newspaper, the South China Morning Post (Classified Section). The only criteria used in the selection of cuttings was that the word 'Engineer' should appear on the heading in every case. Sixteen items were selected - as shown in this Appendix. Table below shows the skills that were found to be commonly required for the posts and the concomitant questions in the Stage 3 survey.

<table>
<thead>
<tr>
<th>Tasks/Skills Required</th>
<th>Appearing in Advertisement</th>
<th>Questions Prompted</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD</td>
<td>3</td>
<td>8g,h;11b;12a,c</td>
</tr>
<tr>
<td>China Trade</td>
<td>1,2,9</td>
<td>8c,e;11a;19</td>
</tr>
<tr>
<td>Design/R&amp;D</td>
<td>1,3,5,6,7,13,14</td>
<td>8g;11b;12a;24(i-v),ix)</td>
</tr>
<tr>
<td>Draftsman</td>
<td>1,3,14</td>
<td>8g-j;11b;12a;12c</td>
</tr>
<tr>
<td>Languages</td>
<td>5,8,11,15</td>
<td>11a;12b;12e;19</td>
</tr>
<tr>
<td>Leadership</td>
<td>6</td>
<td>No direct question</td>
</tr>
<tr>
<td>Maintenance</td>
<td>13</td>
<td>8k;11g;24x)</td>
</tr>
<tr>
<td>Management</td>
<td>6,9,12,15,16</td>
<td>8c-e;11a-c;12b;19;24</td>
</tr>
<tr>
<td>Market Study</td>
<td>2,6</td>
<td>8c,e;11a,c;12b;19</td>
</tr>
<tr>
<td>PR skills</td>
<td>2,5,6,8,9</td>
<td>8c,d,g,h;11a;12b;19</td>
</tr>
<tr>
<td>Project Work</td>
<td>1,3,7,10,14</td>
<td>8d;11d,g;12e;24ix)</td>
</tr>
<tr>
<td>Quality Control</td>
<td>15,16</td>
<td>8j-m;11e,g;24v)</td>
</tr>
<tr>
<td>Sales</td>
<td>2,8,9,11</td>
<td>8c;11a;19;24vi</td>
</tr>
<tr>
<td>Standards</td>
<td>14,16</td>
<td>8g,h,m;11b,d,g;19</td>
</tr>
</tbody>
</table>

Skills in Design, Management, Project Work and Languages were common requirements. Compared to the survey results (Chapter 6, Section 2, p. 135-141) the above table displays a similar priorities of skills.

It was evident that 'leadership' qualities were required in only one of the advertisements eventhough public relations (PR) and an outgoing personality were demanded in advertisements 5,6,8 and 9. Therefore, the questionnaire reflected this emphasis on sales and marketing skills.

Further explanations of the adaptation of this data is given in the main text (see Chapter 4, p. 62 onwards). Appendix F, that follows, was also used in the design of Question 11 of Stage 3 of the survey.
PROJECT ENGINEER / DRAFTSMAN

Urgently required by a plastic toy factory in Kwun Tong. Applicant should be a technical college graduate with min 2 years working experience in toy field. Job duties include project follow up work, product and mold design / drafting. Please send detailed personal particulars, include job history, recent photo, telephone number and salary expected to GPO Box 5897 HK (Ref No. 8).

SALES ENGINEERS (HVAC)

The Job

The incumbent will be responsible for the efficient and effective marketing and selling of HVAC products in China markets. This entails technical back up services, follow-up of existing projects, sales forecasts, market study and maintaining close relationship with clients, design institutes and exploring new sales opportunity in Mainland China.

The Person

Applicants, aged 26-40, should ideally be a University graduates with a minimum of 3-4 years post qualification work experience in sales and marketing field and have pleasant and outgoing personality with good selling techniques and interpersonal skills.

Preference will be given to those who had exposure in sales of HVAC products. Effective communication in Putonghua and English will be an added advantage.

MECHANICAL ENGINEER

- Degree In Mechanical Engineering
- One year practical packaging design in OEM products, good drafting skill is required, CAD experience is an advantage but not essential
- Responsible to assist mechanical design team in project design and development work.

MECHANICAL ENGINEER

A very good salary for a man who can do mechanical design on his own for an electronic manufacturer. A B.S. is required along with 4 years experience in electromechanical design. Please send resume, contact phone no., recent photo and salary expected to Box 05227 SCM Post.
following posts:-

(1) SALES ENGINEER
- University/College graduate
- Minimum 2 years direct sales experience in the equipment market
- Outgoing personality and able to deal with people effectively
- Good command of English and knowledge of Mandarin is of definite advantage

Principal Engineer — Director Designate
M & E Services
c. HK$500,000

Our client, a leading mechanical and electrical consulting engineering practice, has numerous on-going projects in Hong Kong, PRC and the region. A unique opportunity has arisen for a high calibre professional to share management and technical responsibilities.

Working closely with the Director, the appointee will be accountable for the results in the following functional areas:
- project management
- technical leadership and support
- engineering and related services
- client relationships
- new business development

The successful candidate is likely to be a qualified professional who has a solid and progressive field engineering career supplemented by an impressive commercial track record attained within the M&E consulting field. Just as important are entrepreneurial flair, ambition, an outgoing personality and the ability to establish constructive, interpersonal relationships. Both local and expatriate professionals will be considered.

The attractive salary offered reflects the importance of this position. Of critical interest to the right person, however, will be a profit sharing scheme designed to reward business innovation and success. With proven business development success a Directorship appointment is envisaged.

Please apply in confidence with full career details, salary history and a telephone number, quoting Ref No. 932, to:

APPLICATION ENGINEERS

to join our successful team.

Application Engineers work on the development of our products to make them suitable for a wider range of uses. The work is challenging and stimulating. We offer excellent pay scales and opportunities to move up our engineer grading system for many other benefits.

Applicants should have Engineering Degrees or Diplomas in Mechanical or Electrical Engineering.

SALES ENGINEERS

Qualifications:-
- Degree in Mechanical/Computer/Architecture/Civil Engineering or equivalent
- Possess 1-2 years relevant sales experience
- Sales-oriented and outgoing personality
- Willing to travel
- Well versed in Mandarin for those work in PRC market
SALES ENGINEER (HK/PRC)

This position has responsibility for Sales & Market Development for our Computer Graphics Plotters in HK & PRC. The individual must have attained a good track record in direct or indirect selling of high technology equipment or other computer related products. The position offers strong potential for advancement within the organisation.

CUSTOMER SERVICE ENGINEER (HK/PRC)

You belong to a field service team responsible for installation and maintenance of component and board testers and development of test programs. You provide on-call service (consultative or troubleshooting at customers' bases) and assist customer management in implementing correct testing strategies and system revision levels.

You should have a Diploma, Degree preferred, in Electronics Engineering and minimum two years industry experience in handling either component or board testing. Fresh university graduates may also apply.

A pleasant personality, service oriented attitude, high degree of willingness to travel extensively to & within PRC are also prerequisites.

Schlumberger offers a highly competitive compensation. Benefits package & excellent career growth potential. Please send your detailed resume and a contact telephone number immediately to:

MECHANICAL COMPONENT ENGINEER (Ref. 345-0D)

- University graduate or holder of Higher Diploma in Mechanical Engineering
- 1 year working experience with exposure to metal stamping process

Assistant Training Engineers

Salary in range $6,105 – $11,120 per month

Working in the Transmission and Distribution Division, main duties will be to identify training needs for the training of trainees and staff in the Division, to organize and co-ordinate training activities, to prepare training programmes/manuals/notes, to conduct courses and to monitor the progress/ performance of on-job trainees and apprentices.

Candidates should possess a degree or equivalent with a minimum of three years industrial experience.

These appointments offer excellent terms and conditions of service including annual bonus, comprehensive medical, retirement and life assurance schemes.

Applications with details of academic achievements, experience to date, present salary and telephone number to:

The Manager (Personnel & Administration)
The Hongkong Electric Co Ltd
PO Box 915 GPO Hong Kong
1. MAINTENANCE ENGINEER
- Male
- Holder of a university degree in Electrical / Mechanical Engineering or Building Construction or Higher Diploma of Hong Kong Polytechnic
- Minimum 3 years experience in Building Maintenance and be able to work independently

We are a fast growing & dynamic manufacturing/marketing subsidiary of a multinational company. We invite qualified personnel to fill the vacancies of:

SENIOR DESIGN ENGINEER
- U. grad. or Dip. in Mechanical/Production/Industrial Engineering.
- At least 3 years practical experience in a responsible position of product design and development.
- Must have good experience in plastic and metal parts design.
- Possessing good drafting skill.
- Preference will be given to those having knowledge in approval standards, eg. VDE, UL, CSA, etc.

An American Computer Peripheral manufacturing company has the following vacancies:

VENDOR QUALITY ENGINEER
- University (Polytechnic graduate in Engineering with not less than 3 years experience in QC or Manufacturing Engineering in Hi-tech products
- to set up Vendor Qualification Procedure
- good command of written and spoken English and Chinese is required

MAINTENANCE ENGINEER
- University/Polytechnic graduate in Engineering with not less than 5 years experience in industrial experience, 3 years of which in Maintenance of modern Electronics/Mechanical equipment
- familiar with electronic control systems and electrical testing
- to supervise a team of technicians

Attractive salary and fringe benefits will be offered to the right candidates, please send full resume stating salary expected and telephone number to:

PERSONNEL OFFICER
12/F PIAZZA INDUSTRIAL BUILDING
133 HOI BUN ROAD, KWUN TONG
KOWLOON

MATERIAL CONTROL ENGINEER
- Degree/High Dip. in P.I.E./Purchase & Supply/ Business Studies or equivalent
- Minimum 1 year relevant experience
- Responsible for material planning and control, forecasting, expediting and to monitor the flow and supply of material and their proper usage
APPENDIX F.

Student Welfare Unit (Hong Kong Polytechnic)

Survey Results
### Course: Mechanical Engineering

<table>
<thead>
<tr>
<th>Position</th>
<th>No.</th>
<th>Monthly Salary ($)</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant Mechanical Engineer</td>
<td>2</td>
<td>3,100-3,200</td>
<td>3,150</td>
<td></td>
</tr>
<tr>
<td>Assistant Project Engineer</td>
<td>1</td>
<td>4,000</td>
<td>4,000</td>
<td></td>
</tr>
<tr>
<td>Engineer</td>
<td>1</td>
<td>3,000</td>
<td>3,000</td>
<td></td>
</tr>
<tr>
<td>Factory Inspector II</td>
<td>1</td>
<td>5,150</td>
<td>5,150</td>
<td></td>
</tr>
<tr>
<td>Graduate Trainee</td>
<td>1</td>
<td>3,500</td>
<td>3,500</td>
<td></td>
</tr>
<tr>
<td>Mechanical Engineer</td>
<td>2</td>
<td>3,300-3,800</td>
<td>3,550</td>
<td></td>
</tr>
<tr>
<td>Sales Engineer</td>
<td>1</td>
<td>4,000</td>
<td>4,000</td>
<td></td>
</tr>
<tr>
<td>Technical Assistant</td>
<td>1</td>
<td>4,552</td>
<td>4,552</td>
<td></td>
</tr>
<tr>
<td>Technical Engineer</td>
<td>1</td>
<td>3,800</td>
<td>3,800</td>
<td></td>
</tr>
<tr>
<td>Technical Officer</td>
<td>1</td>
<td>4,215</td>
<td>4,215</td>
<td></td>
</tr>
<tr>
<td><strong>Sub-total</strong></td>
<td>12</td>
<td>3,000-5,190</td>
<td>3,805</td>
<td></td>
</tr>
</tbody>
</table>

### Course: Mechanical Engineering

<table>
<thead>
<tr>
<th>Position</th>
<th>No.</th>
<th>Monthly Salary ($)</th>
<th>Range</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assistant Design Engineer</td>
<td>1</td>
<td>3,350</td>
<td>3,350</td>
<td></td>
</tr>
<tr>
<td>Assistant Engineer</td>
<td>4</td>
<td>3,500</td>
<td>3,500</td>
<td></td>
</tr>
<tr>
<td>Assistant Mechanical Engineer</td>
<td>5</td>
<td>3,000-3,300</td>
<td>3,180</td>
<td></td>
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The titles in the above chart guided the design of question 11 in Stage 3 of the survey (see Chapter 4 Section 5.3, p. 76 onwards).
APPENDIX G

Letter from the Hong Kong Federation of Industries
Mr. K. K. Chandran,
M&E Department,
Hong Kong Polytechnic,
Hung Hom, Kowloon,
HONG KONG.

Dear Mr. Chandran,

Further to our telephone conversation yesterday concerning the survey you are conducting on professional engineers, I am pleased to attach for your information a copy of the circular which we put out to our members last Friday to solicit their support in completing the questionnaire. They have been requested to return the questionnaire to you direct by early May.

If I can be of further help to your survey project, please feel free to contact me again.

Yours sincerely,

Iris Wan
Assistant Director
(Industry Division)

Encl.
MEMORANDUM TO: All Members

SUBJECT: A survey on professional engineers conducted by the Hong Kong Poly-technic

The Survey

Members are informed that the Hong Kong Poly-technic has launched a research project to identify the numbers, types, training and educational background of engineers working in industry and other organisations in Design or Development areas. A survey of relevant industries in Hong Kong is being conducted to find out the types of careers engineers have progressed through. Their views on the relevance or otherwise of their academic background are sought.

For the purposes of this survey a professional engineer is one who:

i) has a Degree from a recognised institution and is now in relevant employment; or

ii) is a corporate member of the Hong Kong Institution of Engineers or equivalent body; or

iii) has a Higher Diploma and/or Associateship from the Hong Kong Polytechnic.

Federation's Support Sought

The Federation has been requested to assist with the survey which, it is hoped, would provide useful information for the planning of education and training of future professional engineers in Hong Kong, thus enabling more efficient and realistic manpower planning to be made.

The questionnaire used in the survey is reproduced as the appendix, which you are kindly requested to complete and return direct to:

Mr. K.K. Chandran
MIE Department
Hong Kong Poly-technic
Kowloon

For further enquiries concerning the survey, please contact Mr. Chandran at K-656314, Ext. 768 or 767. The deadline for reply is early May.
通告編號：85/52

一九八三年四月十八日

備忘錄致：全體會員

主旨：香港理工學院開展專業工程師調查

香港理工學院為了制訂更有效更切合實際的教育計劃和專業工程人員訓練計劃，已開展一項專業工程師調查，以了解現正服務工業界及設計與研究機構的工程師的人數、類別、教育及訓練背景、他們所從事的職業等等。列入調查範圍的專業工程師是指以下人士：

1. 已取得認可專上學院學位，現正在上述行業就業者；或

2. 香港工程師學會的會員或同類社團的成員；或

3. 已取得香港理工學院的高級文憑及（或）在理工學院有教職者。

所請各會員鼎力協助是項調查工作，提供有用資料。茲複製附著是項調查的問卷，請妥遞於三月上旬填妥，

按址寄還：

Mr. KK Chandran
MME Department
Hong Kong Polytechnic
Hung Hon
Kowloon

倘有查詢，請電洽電話3-638344內線768或761，

同理工學院Chandran先生聯絡。

248
Mr. L. A. Chandran,
ME Department,
Hong Kong Polytechnic,
Kung Roa,
Kowloon.

Survey on Professional Engineers
(Circular No.: 55/52)

Organisation details:

1. Name of organisation and address:


2. Name of person completing the form:
Mr./Dr./Ms. ____________________


3. Position: ____________________


4. Total number of employees: ____________________


5. Number of Graduates (all disciplines) employed: ____________________


6. Total number of professional engineers - (ref to part 1 of the covering circ. card):


7. How many of your professional engineers are graduates of:
   a) Hong Kong University ____________________
   b) Chinese University (HK) ____________________
   c) Hong Kong Polytechnic (Higher Diploma & Associateship (HND)) ____________________

8. How many of your professional engineers are graduates of:
   a) a UK university ____________________
   b) a US university ____________________
   c) Australian University ____________________
   d) a University in China ____________________
   e) other countries ____________________

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1. How many of your professional engineers are Corporate members of any of the following Institutions?
   a) Hong Kong Institution of Engineers
   b) Any professional Institution in TA (e.g. Institute of Engineers, AAAE, ICE, IEE)
   c) Australian or New Zealand Institutions
   d) Other (please state country)

2. Number of professional engineers employed in design/development/research/modification
   i) Number involved in design
   ii) Number involved in development
   iii) Number involved in research
   iv) Number involved in modification

3. If none of the above describes the work carried out in your organisation state briefly work you do and consider relevant to areas in question 1a) to 1d). (If more than one area is identified please state them separately and give number employed in each area)

   No of Professional Engineers

(Please state number employed in each area)

4. How long has your Design Function (or related area as per question 1c) been in existence in Hong Kong?
   (Please tick appropriate one)

   Less than one year
   between 1 and 5 years
   between 5 and 10 years
   between 10 and 15 years
   over 15 years
13. Does your organisation expect (or plan) over the next ten years, the design related areas to:
   a) expand
   b) be reduced
   or c) remain as it is now?

14. Do your professional engineers have access to computers of any kind?
   YES/NO

15. Are the computers used:
   - mainframe units supporting terminals
   - microcomputers
   - both mainframe & microcomputers

16. Does your organisation follow any of the following standards in the design process? (Please tick appropriate one(s)).
   BS
   DIN
   JIS
   ISO
   American
   Australian
   other(s) please state type(s)

17. How many of your professional engineers are working for higher degrees/qualifications?
Please list below names of professional engineers in your organisation whom you would nominate for a detailed survey:

<table>
<thead>
<tr>
<th>NAME</th>
<th>TEL NO</th>
<th>ADDRESS</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
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</table>

Any comments:
APPENDIX H

Question 9 - Tally and Summary
9. PLEASE READ INSTRUCTIONS CAREFULLY

Rate the following subjects studied at first degree level:

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<thead>
<tr>
<th>Subjects</th>
<th>very useful</th>
<th>useful</th>
<th>not useful</th>
<th>not studied</th>
<th>never</th>
<th>once only</th>
<th>more than once</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering Drawing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mathematics</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
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<td>Computing Studies/Programming</td>
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</tr>
<tr>
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<td></td>
<td></td>
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</tr>
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<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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Appendix
APPENDIX J

Table of Tally Additions
9. PLEASE READ INSTRUCTIONS CAREFULLY

Rate the following subjects studied at first degree level:

i) In the past five working days how many times have you used this subject?

ii) If you have not studied this subject, mark here

iii) How useful this subject in your work?
Tick appropriate box for each subject

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<th>not useful</th>
<th>not studied</th>
<th>never</th>
<th>once only</th>
<th>more than once</th>
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<td>7</td>
<td>17</td>
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<td>Automatic Control/Instrumentation</td>
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<td>2</td>
<td>3</td>
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<td>5</td>
<td>18</td>
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APPENDIX K

Examples of Concept Mapping in Literature Survey
This section discusses the features of the concept maps that are presented as examples for beginner students in the use of this technique. The maps shown follow general conventions used in the literature. Propositional lines are labeled to facilitate comprehension [Ault, 1985]. The maps are, generally read from top to bottom. The mapping process as described by Ault in detail [1985] is used (see pp. 89-94 in main text) in presenting this as an example. As an example, the map titled 'Concept Map One: Whole Unit' in this Appendix is presented here.

This map from Cliburn [1985] has the Skeletal System as the most inclusive concept. Under this general topic various items that relate or explain the focus topic are given in the encircled definitions in the map. These are 'ranked' according to their inclusiveness and abstractness.

Concepts are 'clustered' if they function at a similar level of abstraction and interrelate closely (each defined in terms of the other, for instance). This stage reflects judgement about closeness of association.

A rank and cluster listing of the contents of this map is shown below.

**Most Inclusive Concept**

Skeletal System

**Highly Abstract Concepts**

Anatomy

Physiology

**Abstract/Concrete Concepts**

Bone Tissue

Bone Organs

Main Divisions

Developments

Calcium Homeostasis
These concepts are arranged in a two-dimensional array analogous to a road map. Each concept is, in effect, an area that the learner needs to understand if the focus statement is to be clearly understood. In this case, the study of anatomy and physiology are essential for the understanding of the Skeletal System.

The positioning of these concepts relative to one another is a dynamic process. The learner may need to include further concepts to clarify existing ones. Revisions of the set up may be necessary to define routes to other related concepts. This revision may even involve the altering of rank or cluster elements or even the focus concept itself.

Once the two-dimensional array is ready, the concepts can now be linked and each linking line can be labeled in a propositional or prepositional form. In this example, the study of physiology explains the 'function' of the Skeletal System whereas anatomy deals with the 'structure' of the system. The linking continues till as many interlinks as possible are established.

The map from Loncaric [1986] is very simple in this sense. The links are all vertical and there are no horizontal links shown. This is perhaps not surprising since these were drawn by 6th grade social studies students in the USA. A college student would have many horizontal links - for example, tree roots linked to water and trees linked to rain.

Ault's and Cliburn's maps are more complex and comprehensive and were useful in demonstrating to engineering students the usefulness of this
technique in their work.

The completed maps represent an understanding of all the important concepts within a focus statement. Further, this understanding can be communicated to others through the maps.

The student's work on engineering concepts is discussed in detail in Chapter 5 and presented in Appendix L. Their view of an engineering professional in concept map form is presented in Appendix M.
Fig. 2. Concept Map One: Whole Unit
Figure 5.8: Huna Concept Map constructed from Hala'au research 1972. These concepts led to the development of the interview format for Huna operators.
Figure 5. Completed map for the sample text passage introducing sea floor spreading.

Ault (1985) p 4
Lončaric (1986), p51
Figure 2.1 A concept map for water showing some related concepts and propositions. Some specific examples of events and objects have been included (in Roman type outside ovals).

Novak (1984) p16
APPENDIX L.

Student's Concept Maps of Engineering Components

and the Author's Training Maps
Presentation of the Author's Maps

The author attended a one-day course in concept mapping technique at the Hong Kong Polytechnic's Educational Technology Unit. The aims were twofold - firstly, to get some guidance on the application of the technique in different knowledge areas and secondly (and more importantly), to get a first hand experience of the novice student's position when attempting this for the first time.

The session was one of a 'suck-it-and-see' type. A small group of 6 staff from various department were present and the first task was to draw a map of 'Teaching' - see Concept Mapping Exercise (CME) 1.

This turned out to be a very simple one with only vertical links and was considered to be 'not general enough'. The group progressed through two further maps and the CME 3 brought in the complex horizontal links that were necessary to explain the subject of Engineering Design.

The last map (CME 4) was of the author's department and involved the study of the administration and management of the resources. This map was subjective and 'ranking' and 'clustering' were not possible.

Important lessons learnt were:

- The technique is valuable in all spheres of knowledge.
- Each map is unique.
- Knowledge and understanding of subject matter is assessable after the exercise - even if it only identifies the areas not understood.
- Externalises ones views clearly.
- Stresses areas otherwise ignored.
- Anyone can develop a concept map on any subject - maps only externalises one's views on a subject.

Presentation of Student Concept Maps

The details of the strategy employed in the student concept mapping exercise are described in Chapter 5. This appendix shows samples of student work and also gives a presentation of one of the maps to illustrate the
relevant details.

The four maps shown are typical of the submissions. The format was similar - maps drawn from a function point of view. Some were purely functional (e.g. one on Fastening) while others showed interlinking concepts (e.g. Motors map). There was clear evidence of students not venturing into any abstract statements - in terms of engineering (e.g. aesthetics, cost-effectiveness, safety, reliability, strength/weight ratio) - and were content to describe the technical details only. This was accepted at this stage as this was only an introduction to the technique.

Three such components were examined by each group. This was considered sufficient as indicated by the literature (see Chapter 5, p. 92).

Students then progressed to the mapping of a professional engineer and this is discussed in Appendix M.
Concept Mapping Exercise - 2

- Beam formation of beams
- Analysis
- Types of beams
- Ends:
  - Simple
  - Fixed
  - Continuous
  - Cantilever

- Supports:
  - Types
  - Simply
  - Fixed
  - Continuous
  - Cantilever

- Materials:
  - Types
  - Machinability
  - Castability
  - Strength
  - Stability
  - Life

- Assembled, bolted, riveted, welded, cast, other methods
APPENDIX M

Student Concept Maps of Professional Engineer
Presentation of Student Concept Map

The results of the student concept maps of a professional engineer are discussed in general in Chapter 5, p. 98-106. This section presents one of these maps.

The map considered here is marked 'A' in this Appendix.

Like all other maps submitted this one places the engineer at the centre and his activities and attributes are scattered around this core. The map clearly evolves from the core to the outer areas - from the activities to the training needed for these.

The inner ring of skills - the first rank and the cluster of skills includes:

*Team Work, Design, Boosting Hong Kong industries, Draftsman, Quality Assurance, Management, China Trade, Aesthetics, Low Cost Automation.*

This cluster is linked to the next cluster of attributes which include:

*CAD, Social Concern, Modal Analysis, Communication Techniques, 3D Vision, Hong Kong 1997 (History), Art, Architecture.*

This particular map went on to detail areas of the course that help or stimulate the development of these skills, attributes and characteristics. Constant reference to 3rd year course work is made. Design is mentioned and is brought into design for production.

Problem Solving is highlighted under design and decision making is classed as important in management. Leadership and organisation is listed while professional ethics relate to environmental issues. International trade relations is also specified as an important role for an engineer. China trade, politics, social concern and languages are brought into the map.
The individual items in the maps were collated and the items are listed on p. 103-104 in the main text.

While the maps were excellent in describing the professional engineer, there were no cross linking (horizontal links) of the skills involved. In some cases, however, these links were implied by the same concept stated at the end of different routes. For example, in map ‘A’, 3rd year training appears at the end of four routes, thereby establishing cross links. In map ‘C’ such a link could be justified in the route marked on the map during assessment.

There were some questionable statements. In map ‘D’, under the primary concept of Research and Analysis, the concept of problem identification was considered "very rare"! Such items added to the urgency of developing a model for curriculum in design.
APPENDIX N

Matrix Model for Survey
Dear Director

Dr John Clark

Date our ref. your ref.

Design Engineer – a Curriculum Model

First, thank you for taking part in the earlier survey of Engineers in Hong Kong. The purpose of this letter now (and the enclosures) is to request your assistance with the research I am currently conducting in fulfillment of a doctoral requirements at Surrey University, U.K. The research is intended to explore and identify the skills needed for an engineering designer and from this develop a curriculum model for our BEng programme. The significance of the research is interesting in the continuing demand for engineers capable of moving comfortably into the Design activity in Industry after graduation.

The starting point in this research was the identification of skills and this has been completed and I thank you for your kind cooperation in that exercise.

In order to complete the study I need your assistance once more – for the last time, I promise you. Please refer to the enclosed sheets. This includes:

a) a sheet with model
b) a sheet with some definition, and
c) a sheet with 14 propositions

Study the model and the interactions as shown; use the definitions given or consider your own and consider the propositions formulated.

Now, please feel free to alter, modify or re-arrange the items and connections and correct the propositions, if you feel any are wrong, misleading or understated etc.

Once you are satisfied with your modifications and corrections to the proposals, please mail your suggestions (even the originals with comments on them will do) in the self-addressed envelope before the 01 June 1987 deadline. Confidentiality of all comments will be preserved.

Thank you, again, for your kind co-operation.

Sincerely yours,

K. K. Chandran
Senior Lecturer
Department of Mechanical and Marine Engineering
SKILLS INTERACTIONS FOR ENGINEERING DESIGNER

TECHNICAL AND PROFESSIONAL COMPETENCE

SOCIAL IDENTITY STATUS

KNOWLEDGE

Creativity

Problem Solving

Critical Thinking

Engineering Science

Engineering Judgement

ENVIRONMENT

Leadership Autonomy

Ethics

Integrity

Self Confidence

Self Efficacy

KK Chandran
MME Dept., Polytechnic
Hung Hom, Kowloon, Hong Kong
Tel:(K) 638344 x 768
Skills Interactions for Engineering Designers - Some propositional statements

The propositions relate to the link-line numbers shown in the model.

Please read the statements in conjunction with the model: "Skills Interactions for Engineering Designer", Model: Mark 1. [Enclosed in separate sheet].

1. Technical problem solving ability is dependent on knowledge of discipline subject matter.

2. Engineering judgement is influenced by the awareness and understanding of up to date knowledge in the discipline.

3. Critical thinking is a generic skill - can be transferred across all subject area.

4. Greater the ability to think critically, greater the ability to solve problems.

5. In engineering practice critical thinking affects the accuracy of engineering judgement.

6. Engineering judgement mediates between the designer and the constantly changing environment.

7. Accuracy of engineering judgement and perception increase problem solving ability.

8. Problem solving is significantly dependent on acquired skills - which are a result of the designers' previous experiences and interactions with his environment.

9. The more creative the designers, more autonomous they are and greater their ability to lead.

10. Creative designers are self-confident persons and are able to organise and execute courses of action to achieve set goals.

11. Designers with a sense of responsible autonomy are able to make decisions and cope with consequences of their actions.

12. Higher the level of integrity, the greater the perceived autonomy of the engineering designer.

13. Self confidence breeds autonomy and fosters leadership qualities.

14. (a) Logical and critical thinking are related to ethics and moral standing of the engineering designer.

(b) Greater the critical thinking ability, the greater the autonomy of the engineering designer.
There is no universal definition of critical thinking. But one is - persistent efforts to examine any belief or supposed form of knowledge in light of the evidence that supports it and the further conclusions to which it tends. (Glaser, 1941)

Engineering judgement:
Is a uniquely important functional aspect of thinking that allows persons (designers) to cope with, or adapt to, uncertainty. (Rappaport & Summers, 1973) (my parenthesis, not original)

Creativity:
Process of bringing something new to birth. (May, 1959)

Self-efficacy:
How well one can organise and execute a course of action and continue in conditions of uncertainty and stress. (Bandura, 1980)

Autonomy:
Independence, identity and authority - the ability to make choices and handle consequences of one's actions. "Assume autonomy of judgement of his own performance" (Schein, 1972, p9)

Integrity:
Valid internally consistent beliefs that provide at least a tentative guide for behaviour based on the moral and ethical standards of the profession.

Now, please feel free to amend the model and any of the propositional statements - you may work on the original sheets or use others. You may want to:
- Cut out what you feel is wrong
- Put in what you feel is missing
- Link skills as you feel fit
- Add links or re-route the existing ones
- Re-position any of the boxes
- Redefine the skills
- Amend/delete/add to the propositions made

I hope there is something left of the original work!!!

Thank you for your efforts and I hope the exercise has kindled in you some curiosity, even though it may be ephemeral, to look at the education of engineers from the point of view of the novice in the profession - the student!!

To those already well versed in the subtleties of educational psychology I sincerely hope the effort was 'enjoyable' and 'worthwhile'!!! Please return all documents (including the originals) perhaps in, say, ten day's time, to:

KK Chandran
Tel: (K) 638344
MME Department, Ext. 768/790/761
Polytechnic, Hung Hom, Kowloon

Many many thanks
APPENDIX P

Engineering Degree Course Details

(Hong Kong Polytechnic, May 1988)
B ENG (HONS) IN MECHANICAL ENGINEERING SUBJECT SYLLABUS

<table>
<thead>
<tr>
<th>Subject Title:</th>
<th>Engineering Design</th>
<th>Average Hours/Week</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Lect. Tut Studio</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yr.1: 0.5 0.5 1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yr.2: 0.67 0.33 1</td>
</tr>
<tr>
<td>Year of Course:</td>
<td>1, 2</td>
<td>Assessment</td>
</tr>
<tr>
<td>Total Hours:</td>
<td>Yr. 1: 60 hrs.</td>
<td>Continuous: 100%</td>
</tr>
<tr>
<td></td>
<td>Yr. 2: 60 hrs.</td>
<td></td>
</tr>
<tr>
<td>Prerequisites:</td>
<td>Yr.1 Industrial Centre Training</td>
<td></td>
</tr>
</tbody>
</table>

**Aims**

The overall aims of the course are to acquaint the students with the approach and techniques in engineering design, and the applications of engineering knowledge in design development, analysis, detailing, and presentation of information.

**YEAR 1:**

**Objectives**

The first year of the Engineering Design course is focused on the Finniston EAI aspects, providing knowledge and experience in basic design tools and processes, selection of materials for engineering components, cost and process consideration in production of parts, and the applications of standard components in their design. In addition to EAI practice, students will be guided in the application of engineering principles in design of components and simple devices, and the application of computer as a tool for the analysis of component design and in the production of component drawings.
To ensure integration with other subjects in the course, the first year program includes an introductory description of basic technical artefacts based on a comprehensive list of these artefacts, classified according to their functions. The teaching of all engineering science subjects will be interpreted by the students as a progressive building up of his understanding and methods of analysis on these artefacts, which in turn contributes to related practical work in design.

Keyword Syllabus


Textbook


Reference


YEAR 2

Objectives

The second year of the course is dedicated to the development of the student's understanding and competence in the innovative aspects of design. Formal considerations of design methodology is commenced, with the objective of allowing the student to develop a logical and systematic approach to design work and the ability to identify the key factors affecting the success of their design ideas. In addition, in this year of study, students will be provided with further knowledge and experience in design of mechanical engineering products and systems, and the applications of various engineering and computer-aided techniques in the refinement of their work.
Keyword Syllabus

Product development process and design specifications. Design ideas: design problem identification; formulation of design ideas; feasibility study; evaluation techniques. Design refinement and optimization: value engineering analysis; design for automated production and assembly. Computer-aided design modelling and analysis. Simple products and systems design: mechanical power, force and motion transmission system; fluid power and transmission system.

Textbook


Reference

# Detailed Syllabus

## Year 1:

<table>
<thead>
<tr>
<th>Number</th>
<th>Topic</th>
<th>Approximate Durations (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td><strong>Introduction</strong></td>
<td>Lecture: 3</td>
</tr>
<tr>
<td></td>
<td>The role and importance of Engineering Design in industry. Relationship of Design to other engineering and commercial functions. Outline of design process. Design office organization and procedures. Design tools — sketching, drawing and modelling.</td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td><strong>Component Design Technology</strong></td>
<td>Lecture: 3 Tutorial: 4</td>
</tr>
<tr>
<td>3.</td>
<td><strong>Functional Elements</strong></td>
<td>Lecture: 2</td>
</tr>
<tr>
<td></td>
<td>Concepts. Outline of elements for motion, force, joining, lubrication, heat generation, heat transfer and insulation, energy storage, change of pressure, ventilation, and materials handling.</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td><strong>Common Engineering Components</strong></td>
<td>Lecture: 3 Tutorial: 2</td>
</tr>
<tr>
<td>5.</td>
<td><strong>Computer-aided Drafting and Design</strong></td>
<td>Lecture: 4 Tutorial: 4 Studio: 10</td>
</tr>
<tr>
<td></td>
<td>Introduction to computer-aided drafting and design. Hardware and software requirement. Creation of geometry, editing, and dimensioning. Graphic work using BASIC or PASCAL computer language. Simple exercise in application of computer in design.</td>
<td></td>
</tr>
</tbody>
</table>
### Year 1:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Approximate Durations (hrs)</th>
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</thead>
<tbody>
<tr>
<td><strong>6. Design Practice</strong></td>
<td></td>
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</tbody>
</table>
| Work will be undertaken in groups and as individuals. The emphasis will be on the application of academic and design knowledge in the design of components, and the presentation of engineering information. Two short individual project plus one major group project will be undertaken. Sketching and computer-aided drafting will be used in their work. | Tutorial: 5  
Studio: 20 |

Total:  
Lect.: 15  
Tut.: 15  
Studio: 30
<table>
<thead>
<tr>
<th></th>
<th>Topic</th>
<th>Approximate Durations (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Design Method</td>
<td>Lecture: 2</td>
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<tr>
<td></td>
<td></td>
<td>Tutorial: 2</td>
</tr>
<tr>
<td></td>
<td>Product development process. Identification of basic requirements and</td>
<td></td>
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<tr>
<td></td>
<td>development of design specification. Design ideas - the search</td>
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<td></td>
<td>for alternatives; feasibility study and evaluation of alternative.</td>
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</tr>
<tr>
<td>2</td>
<td>Design Refinement and Optimization</td>
<td>Lecture: 6</td>
</tr>
<tr>
<td></td>
<td>Introduction to value engineering and analysis. Economic implication</td>
<td></td>
</tr>
<tr>
<td></td>
<td>of design costing and cost analysis. Optimization - overview of</td>
<td></td>
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<tr>
<td></td>
<td>optimization techniques in design work; linear programming; network</td>
<td></td>
</tr>
<tr>
<td></td>
<td>optimization; optimising non-linear relationships; applications.</td>
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<td></td>
<td>Manufacturing considerations in component design - design for mass</td>
<td></td>
</tr>
<tr>
<td></td>
<td>production, automated production and assembly.</td>
<td></td>
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<tr>
<td>3</td>
<td>Computer-Aided Design</td>
<td>Lecture: 6</td>
</tr>
<tr>
<td></td>
<td>Computer-aided drafting - application to detailed design; parts and</td>
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<tr>
<td></td>
<td>materials database; data acquisition and information system.</td>
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<tr>
<td></td>
<td>Computer-aided modelling - surface and solid modelling, application</td>
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<tr>
<td></td>
<td>in design. Finite element analysis application in stress and</td>
<td></td>
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<tr>
<td></td>
<td>deformation analysis, heat transfer, and fluid flow design problems.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Application of computer in design optimization.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Products and System Design</td>
<td>Lecture: 6</td>
</tr>
<tr>
<td></td>
<td>Introduction to product and system design - design approach; system</td>
<td></td>
</tr>
<tr>
<td></td>
<td>engineering concept. Mechanical systems - power, force, and</td>
<td></td>
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<tr>
<td></td>
<td>motion transmission; mechanisms. Fluid systems - power, motion and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>mass transmission; design of automated system using hydraulic of</td>
<td></td>
</tr>
<tr>
<td></td>
<td>pneumatic systems.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Design Practice</td>
<td>Studio: 20</td>
</tr>
<tr>
<td></td>
<td>Two individual short projects and one major group project will be</td>
<td></td>
</tr>
<tr>
<td></td>
<td>undertaken by students. The emphasis will be on the formulation and</td>
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<tr>
<td></td>
<td>selection of design ideas and refinement of design with the</td>
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<tr>
<td></td>
<td>knowledge and techniques that the students have learned in this</td>
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</tr>
<tr>
<td></td>
<td>and other academic subjects.</td>
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</tr>
</tbody>
</table>

Total: Lect.: 20  
Tut.: 10  
Studio: 30