ENGINEERING EDUCATION FOR THE 21ST CENTURY

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ABSTRACT
The universities perform three distinct functions. Curriculum is the part which involves the function of supplying specialized competence. Engineering education entered the university only after it became a profession. The early curricula therefore were evolved ones which mainly catered for the then contemporary needs of the industry/profession. The rapid developments and advancements in engineering after the Second World War brought in several new disciplines in engineering and designed curriculum became dominant. A methodology for designing the curriculum also was explored. The elements in curricula were influenced by several factors. Researchers in the meantime have identified the mechanism of learning and experiential learning has gained recognition. Embracing these findings a new methodology for curriculum design for the 21st century has been developed.

1 INTRODUCTION

It has now been widely accepted that education in the university plays an important role in the formation of the individuals and hence the society. The universities essentially perform three functions: They are

1. Supplying specialized competence
2. Acting as guardians and repositories of trustworthy knowledge and as partners in the advancement of knowledge through research
3. Making the students enlightened and morally upstanding human beings and leaders of the societies

With regard to Engineering the universities endeavor to continue to produce engineering graduates for the top and elite positions in engineering and to give those involved a chance to feel valuable and self fulfilled in their community Universities achieve these by devising a curriculum. In this context modern engineering can be defined as the combination of scientific principles and technology developed from the experience of doing by means of mathematical systems. This is illustrated in Figure 1.

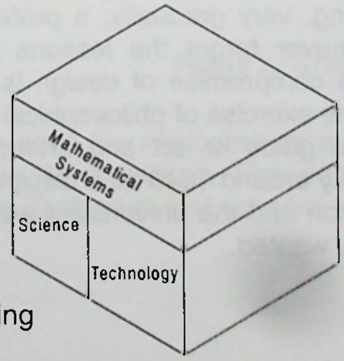

Figure 1: Modern Engineering

Similarly Curriculum is the organized set of content and activities that a university uses as a basis for educating the students. Engineering in the recent past has witnessed several advancements and as a results the curriculum and its design has become a challenge to the academe. This paper briefly looks at the profession and its development, engineering in the university or the curriculum driven engineer and a methodology for developing the curriculum and the teaching or delivery methods for the 21st century. Section 2 looks at the historical development of the profession and its emergence as a discipline in the university together with influencing factors of the curriculum elements. Section 3 looks at the curriculum design methodology and delivery methods. In section 4 a new methodology for curriculum design suitable for the 21st century is described.

2 ENGINEERING CURRICULUM

2.1 Background

Historically engineering started as a craft. Craftsmen everywhere in Europe learnt their art by serving an apprenticeship with a master under well-regulated terms established by the craft guilds. Even medical practitioners and lawyers were trained through a system of apprenticeship although education, at least of university level, was the requisite for these professions. The medieval engineer is a military officer who specialized in the construction of all the appurtenances of siege warfare, fortification and fortresses and the engines of war – catapults, battering rams and the like. He is also responsible for military mining operations and of course any road making or bridge building that came in his way. The engineer had to know why and had to be very sure of how. The first formal education of engineering started in France with the French Artillery School. The British Military Academy was started in 1841 when engineering had already been transferred to the civilian arena. Although France produced a cadre for military engineers and mathematical analysis, it was in England where the Industrial Revolution took place. Education for the Industrial Revolution in Britain was largely a matter of individual enterprise. The British Engineers of this generation who led the Technological Revolution were first and foremost practitioners. Clubs, Societies and Institutions were the main centers for advancing Engineering knowledge. Examples of this kind of organizations include the Royal Society, Institution of Civil Engineers and the Mechanics Institutes established all over England. With the launch of the Institution of Civil Engineers in 1818 the craft based occupation was becoming, very gradually, a profession with a scientific background but which never forgot the lessons of practical experience on which the ultimate compromise of design is based. A craft becomes a profession when the exercise of philosophical thought and the application of scientific principle guide its art and artifact. Engineering Education entered the university around 1840 as a discipline for teaching. Long after it became a profession and the universities were mainly teaching what the industry of that day wanted.

2.2 The Curriculum Driven Engineer

Until the turn of the 19th Century there was no big difference between the two classical types of industrial engineers, the mechanicals and the electricals. Both followed a significant portion in common. The curriculum provided basically what the industry wanted. In short the curriculum evolved. Looking at the first Lathe made by Moudslay in 1797 and a lathe in the 50's or 60's one could still see a lot of features remaining unchanged. This was the situation in Britain until the Second World War. However things started changing rapidly after the war. Several other disciplines different to the traditional Civil, Mechanical and Electrical engineers started to emerge. Questions like (a) who is an engineer (b) what should be in the Curriculum (c) who should decide it, became prominent. The Period of 'Designed Curriculum' emerged.

2.3 Influencing Factors

The evidence to support the argument that the curriculum should reflect the nation's needs is many. For instance Britain's success in industrial revolution had little to do with the educational institutions while Germany around 1850 was investing heavily on Science and Technical Education. Germany started outstripping Britain around 1890. In Japan more than 80% of the graduates are engineering graduates and this reflects the industrial success of the country. Goals of Education should be in-line with the National Development aimed at enriching quality of life Most important aspect of economical planning is the identification of the types of technical and economic professional skills that the economy needs.

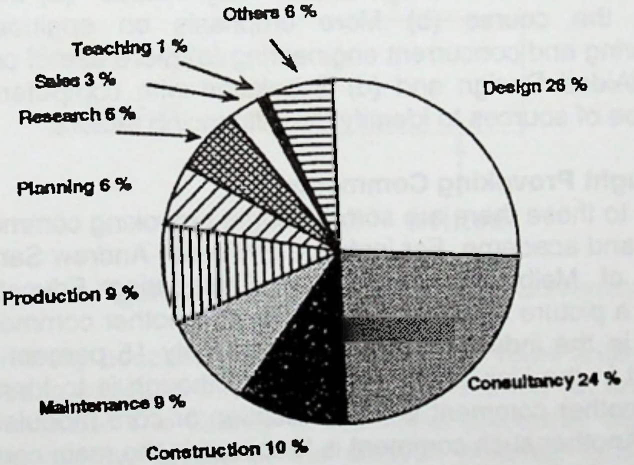

Figure 2: What Engineers Do

Another influencing factor is what the engineers do in their professional work influence the contents in the curriculum. Figure 2 shows the results of a survey carried out in New Zealand to find out what engineers do.

Another way of finding out the opinions of the practicing engineers is to conduct a survey among engineering practitioners on the skills and subject knowledge they require carrying out their professional duties. Table 1 shows the result of such a survey carried out in New Zealand.

Table 1: Importance of Skills

Skill Required	Importance of the skill to current employment 5 - Most important
Ability to communicate efficiently	4.64
Ability to think logically	4.6
Ability to identify imp. features of problems	4.52
Ability to manage your time	4.47
Ability to work under pressure	4.44
Ability to seek out new information	4.4
Confidence in dealing with others	4.38
Ability to work in a team	4.29
Openness to new ideas	4.25
Ability to write clearly	4.17
Ability to work independently	4.14
Ability to work with computers	4.07
Preparedness for continued learning	3.79

There are several learned engineering personnel who have tried to enlist the desired elements in a curriculum. They include (a) Interdisciplinary nature of the course (b) More emphasis on engineering design, manufacturing and concurrent engineering (c) More use of computers and computer Aided Design and (d) Simulation with computers. These are another type of sources to identify the influencing factors.

2.3.1 Thought Provoking Comments

In addition to these there are some thought provoking comments made by engineers and academe. For instance Professor Andrew Samuel from the University of Melbourne states that Engineering Education has not developed a picture of its ideal end product. Another comment states that Engineers in the industry on average use only 15 percent of what they have learnt in the University. The difficulty though is to identify which 15 percent. Another comment is 'Specialisation or core modules? that is the question'. Another such comment is 'Success is the main cause of failure'. A strategy, which worked well to solve a problem successfully once, is often used as a standard method to solve similar problems. But with the march of time the problems and conditions change and the once efficient solution becomes inefficient without the knowledge of the user. This has been the case for Western Manufacturing Sector and the Curriculum in the Universities

There are some very interesting thoughts provoking comments with regard to developing countries. For instance

1. Curriculum development in Developing Countries is more difficult because educators are educated in developed countries who tend to repeat their own curricula'.
2. A student from a developing country is often poorly prepared to begin the study of engineering even after graduating from the secondary school. Such a student has less familiarity with mechanical and electrical equipment and their applications than their counterparts in a developed country. In his surroundings mechanical toys and objects are not in commonplace; hence he is deprived of the acquaintance and knowledge possessed by students in technologically advanced countries. The student's lack of familiarity often makes it difficult for him to relate mathematical analyses to the realities they describe.
3. In a developed country the Concept of Gear Drives is introduced as puzzles instead of as teaching material at the University.
4. The motorcar, 'The Machine that changed the world', a common utility in a a developed country, is a luxury in the developing country. Hence experiences in the development of it, is not available to the developing country students.
5. Advanced technology is introduced as finished goods and the knowledge of development is not given

2.4 University Education as a Value Adding Process

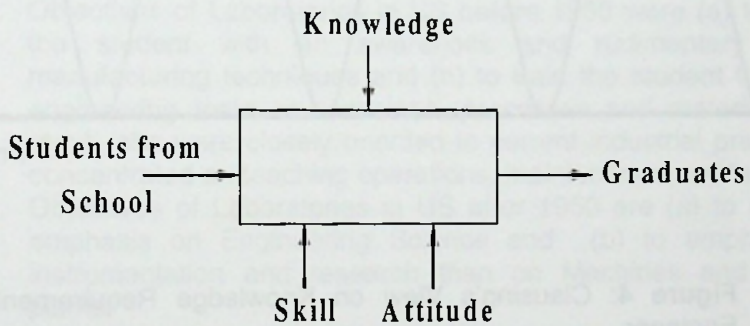

Figure 3 Value Addition Model of University Education

University education can be treated as a value adding process where the value is added in three different ways namely (a) knowledge (b) skill and (c) attitude. The Quality of the output graduates depends heavily on the input quality, quality of the addition process, facilities for the addition process and the quality of educators. The curriculum should reflect all these. This quality is often controlled by having external examiners and by having the degree programme accredited by the institutions. Accreditation lays down norms and standards for courses, curricula, physical and institutional facilities, staff patterns, staff qualifications, quality instructions, assessment and examinations. This ensures periodic evaluation of the institutions and programmes on the basis of guidelines, norms and standards and recommend recognition or derecognition.

2.5 Needs of 21st Century Manufacturing

The 21st Century Manufacturing wants multi-faceted engineering expertise integrated with computational intelligence. Developing countries should gear for producing manufacturing engineers with computer intelligence while developed countries should work for mass customization. This is because the developed countries need much larger volumes of manufacture to break even than the developing countries due to the high cost of labour.

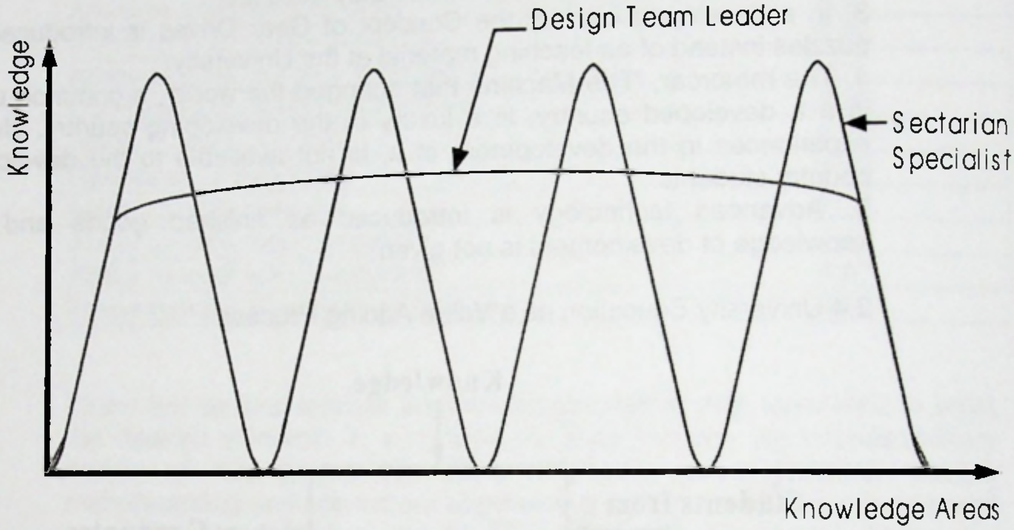

Figure 4: Clausing's View on Knowledge Requirement of a Modern Engineer

Figure 4 shows Professor Clausing's view on the knowledge requirement of a modern design team leader. From the figure it is evident that a person who is good in analysis, or technology or any other sectarian area is not sufficient for the modern industry. As Clausing puts it "You must be a master of several things".

3 CURRICULUM DESIGN AND DELIVERY

3.1 Background

The preceding section outlines the process one has to consider when he or she embarks on Curriculum Design. Grayson outlines a three-stepped methodology for curriculum design. The steps are

1. Problem Definition
2. Structuring the curriculum elements
3. Implementation and Evaluation

The problem definition starts with the following.

1. An analysis of technical manpower needs
2. Needs arising from (a) industrial needs (b) societal needs and (c) professional needs
3. Establishment the desired knowledge, skills and attitude
4. The desired knowledge, skills and attitudes form the Qualification Profile

Curriculum provides the difference between the Qualification profile and the input in terms of (a) Knowledge (b) Skill and (c) Attitude.

The objective of structuring curriculum elements is to achieve the qualification profile by providing learning experiences and to produce a cumulative effect of educational experiences. This is done at (a) macro-level and (b) micro-level. The macro-level process starts with the consideration of the gap between the entry-level student and the Qualification Profile. Continuity, Sequencing and Integration are essential features of modules. End Result of Macro-level Curriculum design is, a syllabus, a timetable and an idea of the teaching approaches (lectures, seminars, lab work etc.). At Micro-level the contents and learning activities are selected and organized to optimize the knowledge gained by the student. This is achieved by the means (a) Computers in instruction (b) Lab work(c) Individualized instruction (d) Self-access media (e) Project and research work. In this context Grayson makes some interesting observations. They are

1. Objectives of Laboratories in US before 1950 were (a) to provide the student with an awareness and rudimentary skill in manufacturing techniques and (b) to train the student to conduct engineering tests on machines, processes and materials. As a result labs were closely oriented to current industrial practice and concentrated on teaching operations, maintenance and testing.
2. Objectives of Laboratories in US after 1950 are (a) to make the emphasis on Engineering Science and (b) to emphasize on instrumentation and research than on Machines and complex plants.
3. Big good Universities still have big workshops on old traditions, which they treasure.

Another observation made by Grayson is the concept of Self-Access Laboratories. All engineering laboratories are combined into a single centre and serve as a library of instruments, testing apparatus and experimental facilities. Students access the facilities whenever the learning activities require them and could use the equipment as long as necessary. He argues that this laboratory will serve the needs of the less exposed students tohave their own pace of learning.

3.2 Delivery

Research in learning habits has identified several interesting facts. Some of them are

1. Students construct knowledge - help them to build on their existing knowledge and experience
2. Students need to see the whole picture - help students to understand and remember new ideas by linking them to make meaningful wholes.

3. Students are selectively negligent - Guide students to prioritize
4. Students are driven by assignment - What is assessed is seen as the most important.
5. Students often only memorize - Most students do surface learning. Only few do in-depth learning. Help them to do in-depth learning.
6. Students' attention is limited - Students lose attention quickly. Give an activity change or a monotony breaker once in ten minutes.
7. Students can easily be overburdened - Not making, listening and looking at the transparency may become too much. Space them properly.
8. Students learn well by doing - Get them to participate and do active learning.

   Students learn well when they take responsibility for their learning

Based on these findings Experiential Learning has been developed.

3.2.1 Experiential Learning

Experiential Learning is the process of engaging the students to make or experiment with artefacts on an individual or group basis, where the student learns one or several skills and knowledge components. It is based on the hypothesis that there are two phases in the educational process: Inputting (learning information and techniques) and Outputting (synthesis, analysis and decision making). The formalized instructional processes take care of the inputting and experiential learning develops the outputting. Experiential learning enhances skills, which include (a) Problem solving skills (b) Interpersonal awareness (c) Creative expression (d) Communication skills (e) Self-confidence building (f) Computation skills (g) Engineering fundamentals (g) Organizational skills (h) Leadership skills (i) Planning skills (j) Professional ethics and (k) Engineering judgement. Experiential learning is categorized into two classes namely (a) Simulations – Carefully designed situations to meet selected learning objectives and (b) Authentic Learning – Exposes to real life problem.

4 CURRICULUM DEVELOPMENT FOR THE 21ST CENTURY

4.1 Background

The broad aim of the curriculum development is to produce morally upstanding and self-fulfilled engineering professionals for the top and elite positions by the supply of specialised competencies. Building on Grayson's work itt can be achieved in the following four steps

1. Problem Definition
2. Structuring Curriculum Elements
3. Implementation, Evaluation & Continuous Improvement
4. Micro-level planning

Figure 5 explains the steps involved and the aims and outputs.

Figure 6 illustrates the steps involved in problem definition and the outputs of this phase of the curriculum design.

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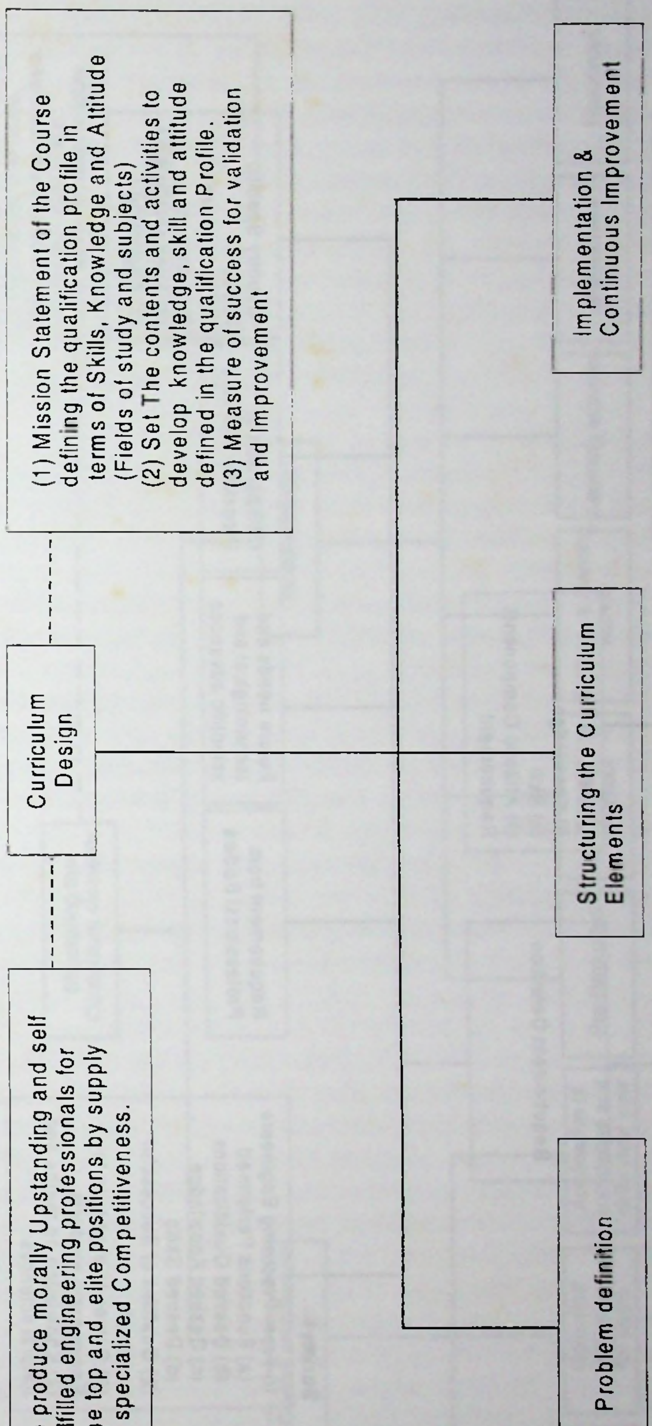

Figure 5: Curriculum Design

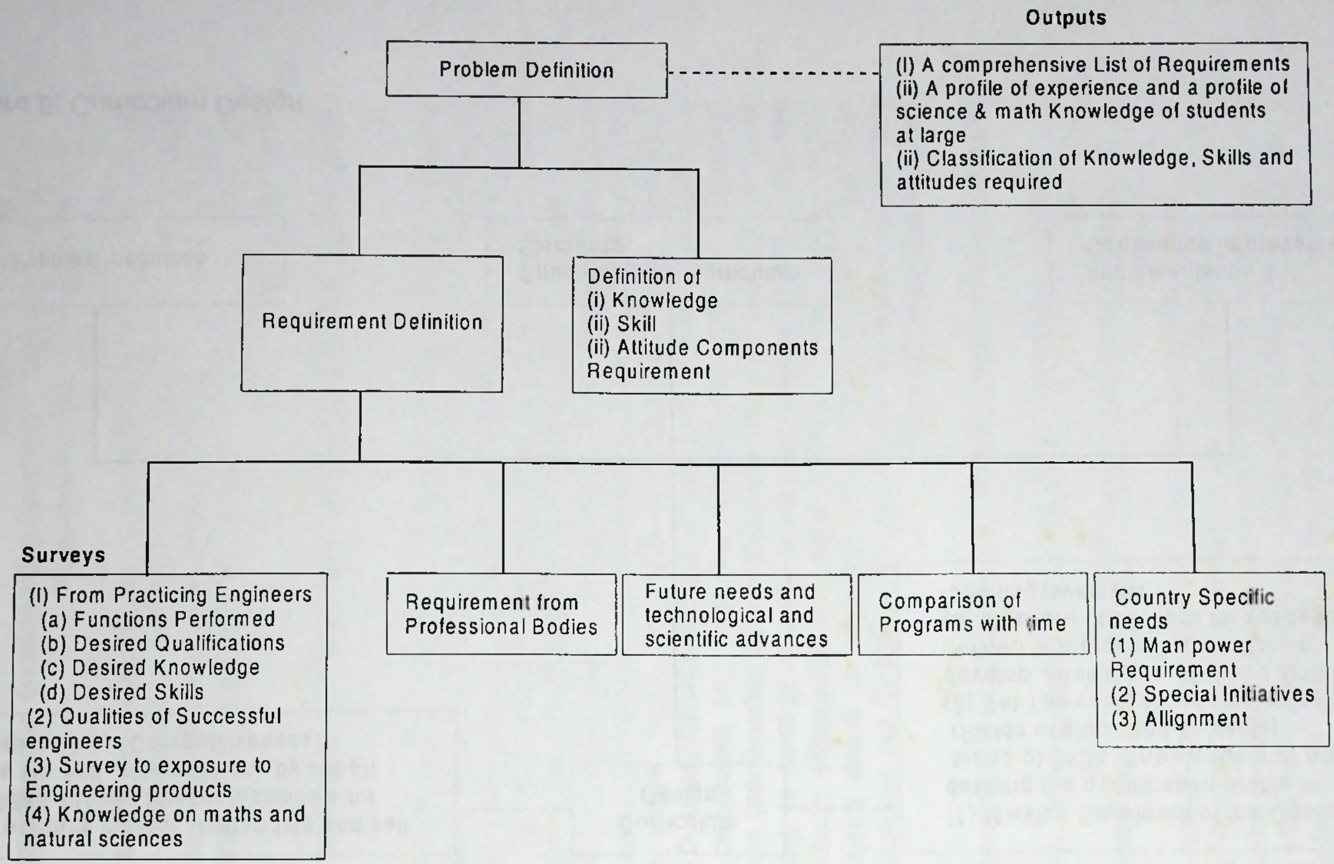

Figure 6: Problem Definition

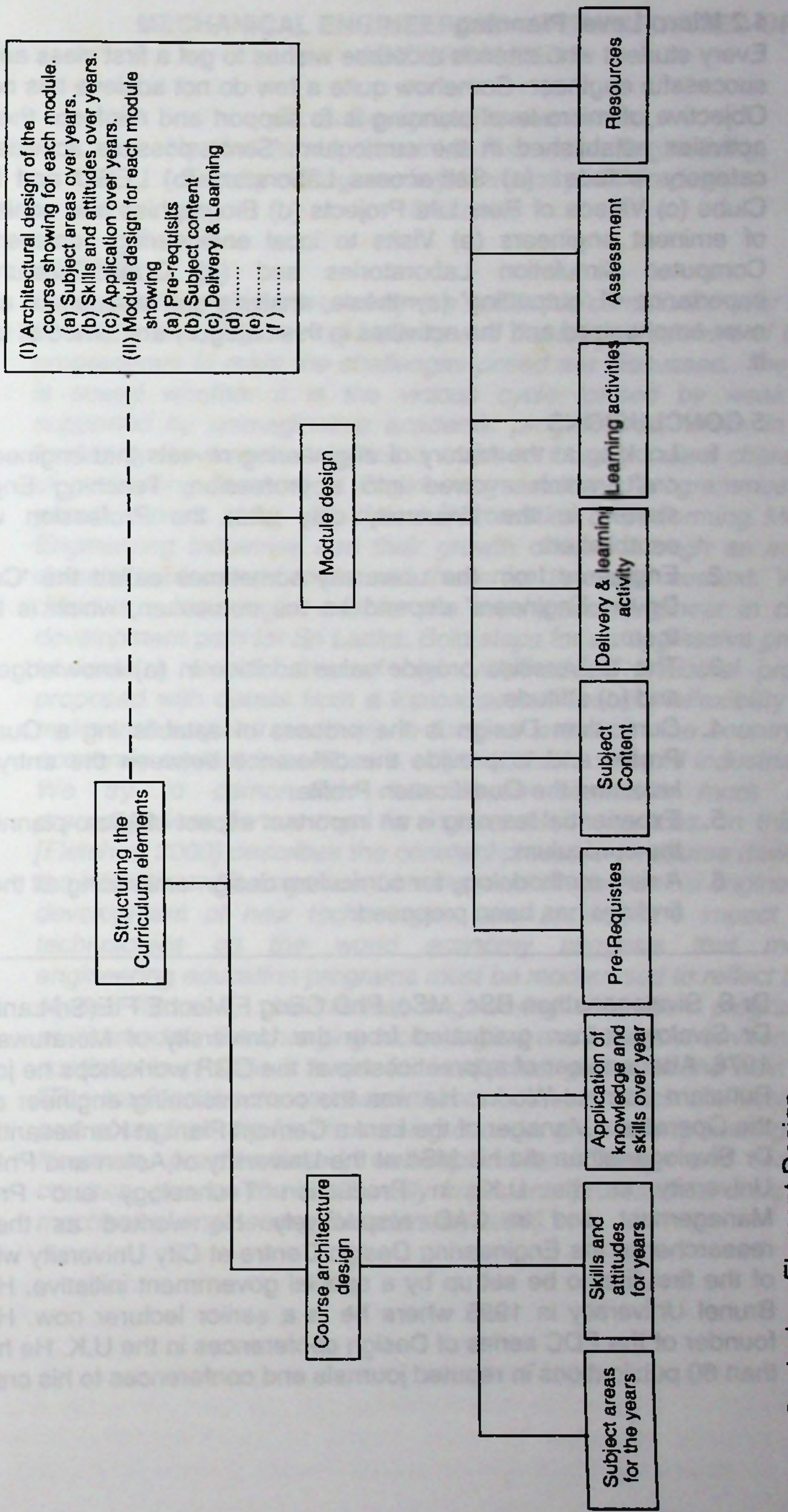

Figure 7: Curriculum Element Design

4.2 Micro-Level Planning

Every student who attends a course wishes to get a first class and to be a successful engineer. Somehow quite a few do not achieve this noble aim. Objective of micro-level planning is to support and reinforce the learning activities established in the curriculum. Some possible activities in this category include (a) Self-access Laboratory (b) LEGO and Mechano Clubs (c) Videos of Real Life Projects (d) Biographies and achievements of eminent engineers (e) Visits to local engineering achievements (f) Computer Simulation Laboratories and (g) Guest Lectures. The importance of 'outputting' (synthesis, analysis and evaluation) cannot be over-emphasized and the activities in this category are aimed at facilitating it.

5 CONCLUSIONS

1. Looking at the history of engineering reveals that engineering is a craft, which evolved into a profession. Teaching Engineering started in the University only after the Profession was well established.
2. Engineers from the university sometimes called the 'Curriculum Driven Engineers' depend on the curriculum, which is taught to them.
3. The Universities provide value addition in (a) knowledge (b) skill and (c) attitude.
4. Curriculum Design is the process of establishing a Qualification Profile and to provide the difference between the entry student level and the Qualification Profile.
5. Experiential learning is an important aspect of Micro-planning of the curriculum.
6. A new methodology for curriculum design embracing all the findings has been proposed.

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Dr Sivaloganathan graduated from the University of Moratuwa in July 1976. After an year of apprenticeship at the CGR workshops he joined the Puttalam Cement Works. He was the commissioning engineer and later the Operations Manager of the Lanka Cement Plant at Kankesanthurai. Dr Sivaloganathan did his MSc at the University of Aston and PhD at City University in the U.K. in Production Technology and Production Management and in CAD respectively. He worked as the senior researcher at the Engineering Design Centre at City University which one of the first five to be set up by a special government initiative. He joined Brunel University in 1995 where he is a senior lecturer now. He is the founder of the EDC series of Design conferences in the U.K. He has more than 60 publications in reputed journals and conferences to his credit.