NEW PARADIGMS IN THE DESIGN OF ENGINEERING CURRICULA

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Abstract

This paper presents *New Paradigms* concerning the design of curricula for engineering degree courses. It sets up the philosophical bases of curriculum design and outlines the Learning Outcomes Theory considered essential for the development of a new consistent pedagogical approach. Some course structures, being so fragmented, are labelled as the cause of the difficulties faced by some engineering courses. An alternative course structure is presented, which allows for the new principles and concepts, and consequently might make advances in engineering education. The proposal is focused on the Systematic Planning Approach and brings an instrument - a Knowledge Based System which embodies the new principles and concepts - to pragmatically assist course designers in the development of their tasks. Some preliminary results from ongoing experiences are discussed.

Introduction

An evolutionary revolution has been taking place in the world due to the impact of technology in general and information technology in particular, both of which are expanding at ever increasing rates. Moreover, the engineers of the next century will face a challenging world which requires a fully prepared professional regarding knowledge, abilities and attitudes. This has brought about an awareness of the need to incorporate new principles and concepts in engineering education where the design of the curriculum plays a crucial role.

Among the new challenges higher education has been facing recently, the Internet is one of the most revolutionary. Since the early nineties when millions started to access the Net it has become a source of learning by many of its users. It is believed that it will not take too long for it to be used as a mass-media in form of formal education, even at tertiary level. Furthermore, the new economic order has been imposing changes in the market place demanding that engineers be prepared to change functions and even careers throughout their professional life span.

This paper addresses these issues by describing a novel methodology of designing curriculum. It advocates that by using a Knowledge Based System as a partner it is possible to achieve a more effective and manageable curriculum design and implementation. The flexibility of the Knowledge Based System is capable of allowing for local, national or international needs which

may vary due to the different contexts of the issues being addressed. A major aspect of this Knowledge Based System is that it fosters a partnership between academia and industry. The paper also discusses the results obtained from experiences being carried out in the institutions where the authors work.

The methodology proposed by this innovative approach encourages engineering educators to follow the various stages of curriculum development, which is suggested to be carried out in a Systematic Planning Approach (Beard, 1985). This is particularly useful for users who have limited experience of curriculum development and may only have specialist subject content expertise. The Knowledge Bases System contains an invaluable asset by incorporating a parallel structure which acts as a tutorial or training package for the users. In this way it educates them in the philosophy underpinning the advice given and prepares them for future curriculum development exercises. This Knowledge Based System has already been successfully tested as a research tool.

Discussion

Higher Education and curriculum development have been evolving relentlessly and more recently under vigorous economic pressures, namely budgetary constraints. The new world economic order, the escalating competitiveness among countries and the need to care for the environment have called out for well educated, multi-skilled and better trained professionals in engineering. Pressure on the Higher Education System has therefore been intensified and educationists have responded to these challenges by coming up with new proposals for education, such as the Credit Accumulation and Transfer Scheme (CATS) and Learning Outcomes Theory (Otter, 1992). In the United States of America there have been some new initiatives to approach this issue such as Concurrent Engineering and Synthesis Coalition (Watson, 1992) and the Carnegie Mellon Electrical and Computer Engineering Degree Course (White, 1995). These initiatives primarily aim at striking a balance between efficiency and effectiveness in developing and running new courses in higher education. Consequently, course developers have faced a huge task when designing new courses to make them accessible to a larger number of students and more flexible in their implementation, while at the same time, not reducing the quality of the learning process. This task of developing courses has been particularly difficult due to a lack of practical guidelines on curriculum design, though theoretical publications abound in this area.

From the point of view of developing countries (also experiencing these pressures) the lack of expertise in curriculum development and the difficulty in accessing practical advice, added to dwindling resources for education exacerbate the problem. It is an international problem (Psacharopoulos, 1991). Also, in these countries, many of the course developers lack the necessary background in curriculum theory, being often industrial specialists newly recruited to education. When a new curriculum is being designed the decision-making process is bound to address specific areas of curriculum development such as: aims and outcomes; course structure; identification of the curriculum content and assessment strategy. Would it not be important to consider that although all these areas related to the curriculum may be looked at independently they should be treated as part of an integrated domain, as a Systematic Approach to curriculum development would suggest?

With that in mind it is suggested here that a Knowledge Based System can represent an alternative to assist in developing curricula. The Knowledge Based System proposed aims to assist the Course Developers on those relevant issues which may lead to a successful design of the curriculum.

Curriculum Design

As a starting point of the approach developed in this paper it is necessary to clearly define the concept of Curriculum. Often this concept is not well understood being mistaken for a set of course units, their contents and the timetable. The term Curriculum however implies a much broader concept, which can be well described according to Bantock's definition (1980):

> **"Curriculum is the whole set of learning experience the student embodies throughout an active process of developing, in an educational institution, a programme of studies coherently aggregated."**

Course Structure is a major concern for course developers and it is subject to all sorts of different pressures. On the one hand, the costs of staff time to teach in a particular course structure and resources for laboratories, are examples of factors which demand fewer staff-student contact hours and less practical (hands-on) learning experiences. On the other hand: (a) the continuous expansion of the content to be covered (with a soaring number of new topics and techniques brought into the curriculum); (b) the flexibility of the curriculum and options to be made available to students and (c) also a more student-centered approach being recommended in higher education requiring more staff time and more physical resources to run courses. Course developers are consequently responsible for designing a structure which takes account of both sets of pressures. They are also urged to change the pedagogical approach from knowledge-based, focused on the content and teacher-centered to competence-based, focused on learning outcomes and student-centered. This change can be expressed in the diagram of figure 1.

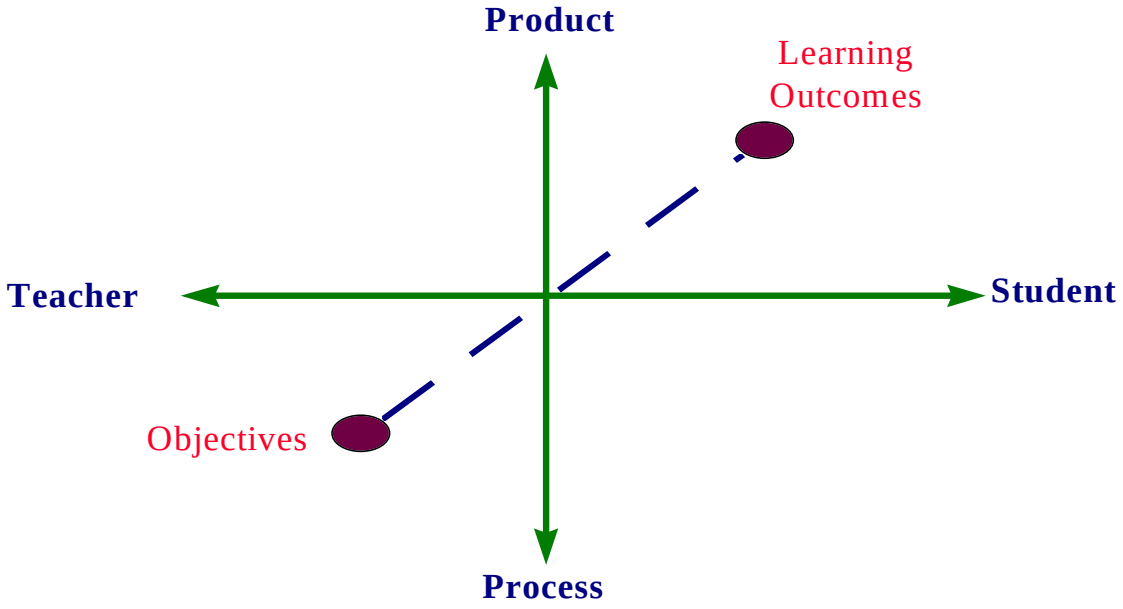

Figure 1 - Change in the Pedagogical Approach

This change in the pedagogical approach results in a new concept facing the degree course which assumes that:

- Learning is the central purpose of education and training;
- The assessment of learning can be better achieved by describing a list of Learning Outcomes.

Principles of Learning Outcomes

This new trend in higher education towards focusing on the students' achievements rather than on the learning process itself has its roots in the Learning Outcomes Theory (Robertson, 1991). It seems to be accepted that this new approach to curriculum development suits best the present requirements of the market place, given that it maps out what graduates are expected to be able to do after having undertaken their learning experience. This theory suggests that a degree course could be described in terms of its learning outcomes. It assumes that achievement is defined by the successful demonstration of learning outcomes and that a group of Learning Outcomes Statements defines the coherent learning experience characterised as a course unit. Some "currency" would be awarded to the student who successfully demonstrated the Learning Outcomes. This approach fosters a stronger link between academia, industry and students. Examples of Learning Outcomes Statements for electrical engineering could be: At the end of the course unit the student should be able to:

> **Apply the basic circuits laws to solve problems in electrical and electronic circuits.**
>
> **Assess the environmental consequences of the flooding caused by the construction of hydroelectric dams**.

The major advantages of using the Learning Outcomes approach can be summarised as:

- Making explicit previously concealed academic, pedagogical and professional values;
- Avoidance of ambiguities;
- Interaction between Learning Outcomes-Assessment-Teaching/Learning Strategies;
- Better communication Student-Student; Student-Teacher; Teacher-Teacher;
- Greater individualization of learning.

Moreover, it is self-evident that the strategy for assessing students' learning cannot be neglected throughout the curriculum design process and plays a crucial role in the Learning Outcomes Theory. It has not always been clear how the assessment procedures actually measure the broad range of qualities expected from engineering graduates. There have been strong criticisms of assessment procedures on the grounds that they lack a coherent theoretical framework and are arbitrary (Otter, 1992). As a result, course developers are put under considerable pressure to come up with a Scheme of Assessment which, within the limits of an institution's resources, represents an appropriate and acceptable measure of achievement and from which students can benefit throughout their courses. The strong link between the Learning Outcomes Statements, the Scheme of Assessment and the Teaching/Learning Strategies can be represented in the diagram of figure 2.

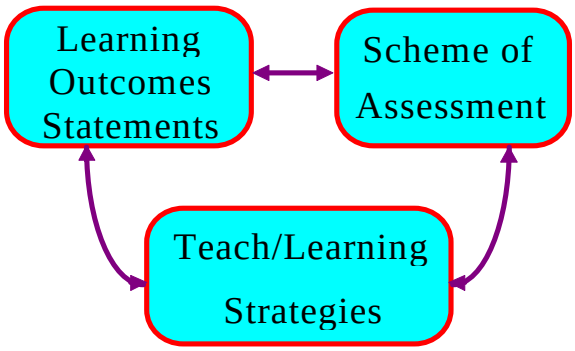

Figure 2 - Links among basic elements of Curriculum Design

Multidisciplinary Courses

Engineering has, nowadays, become a multidisciplinary science and there has been a number of examples where these interdisciplinary fields can be seen such as technology and medicine, computing and philosophy, bioengineering to mention but a few. Therefore engineering degree courses must take into account the following: (a) Humanities Components; (b) Environment Consciousness; (c) Modern Languages; (d) Human Relationship; (e) Management, business and enterprise; (f) Communication and (g) International context.

Engineers of the next century will be required to be less content-based to become competence-based professionals, that is, engineers able to Solve Problems, Make Decisions, Work as a Team and Communicate. Therefore their education process, in particular the curriculum delivered, must have essential characteristics which prepare these engineers to face challenges, be flexible in their functions, be adaptable to new technology, be creative and critical in order to contribute to science and technology as responsible professionals and citizens.

Alternative Course Structures (Modular System)

Course Structure is the framework within which the course units are arranged and it is designed to lead students to a recognized award. Choosing the appropriate structure is essential to achieve a curriculum design that lets the new pedagogical approach to be fully developed. Current course structures used in engineering degree courses are often rigid with no option for the students and these structures leave to the student the intellectual activity of integrating the subjects which, in turn, are delivered in a fragmented fashion. Innovative Course Structures must emphasize ideas and creativity over memorization (White, 1995). They should present an integrated rather than a fragmented view and remove structural impediments (Interweaving). The major characteristics are: be flexible and dynamic; present options from a student point of view; facilitate monitoring and review; allow for articulation with other certificates and present economy of scale.

In this context the paper argues that despite some restrictions the modular structure fulfils, to some extend, the characteristics above and may therefore represent a reasonable alternative. In such a curriculum approach, a module is a course unit comprising a group of learning outcomes statements which defines the coherent learning experience and carries a number of credits.

Students choose, under supervision, from a pool of modules those which will make up their own pathway - programme of studies. In order to be manageable, the modules would be designed as Single, Double (one semester or one academic year long) and Quadruple. The structure of each year in the course design could therefore be a combination of the above alternatives. These combinations were implemented in the Knowledge-Based System described below, and for each year it is possible to have many different combinations.

It can be seen from these sub-areas of Curriculum Development that there is a synergy among the issues discussed which cannot be overlooked if the design of curricula is to succeed in being coherent, efficient and effective. The Knowledge Based System presented in this paper takes these issues into account and may therefore prove to be an essential tool for course developers. Thus this novelty in curriculum design for engineering courses represents an alternative access to curriculum theory, particularly in the areas mentioned. The assumption is that this Knowledge Based System can make a great impact by enabling course design to be improved and by resulting in the better education and training of students for their future professional careers.

The Knowledge Based System

A Knowledge Based System consists of a knowledge base where the expertise (elicited from experts) and the factual knowledge (acquired from the literature) in a specific field (named domain) are stored. The Knowledge Based System makes inference with the knowledge through a set of rules in order to reach a decision. It interacts with the user by asking questions, and giving answers and advice through the User Interface (Jackson, 1990). Therefore it is the combination of the users' input and the embodied knowledge that drives the system to display eventually a suitable advice in the users' context. The domain incorporated in the knowledge base of the System discussed in this paper is that of curriculum development for engineering courses. The main parts of a Knowledge Based System can be seen in figure 3.

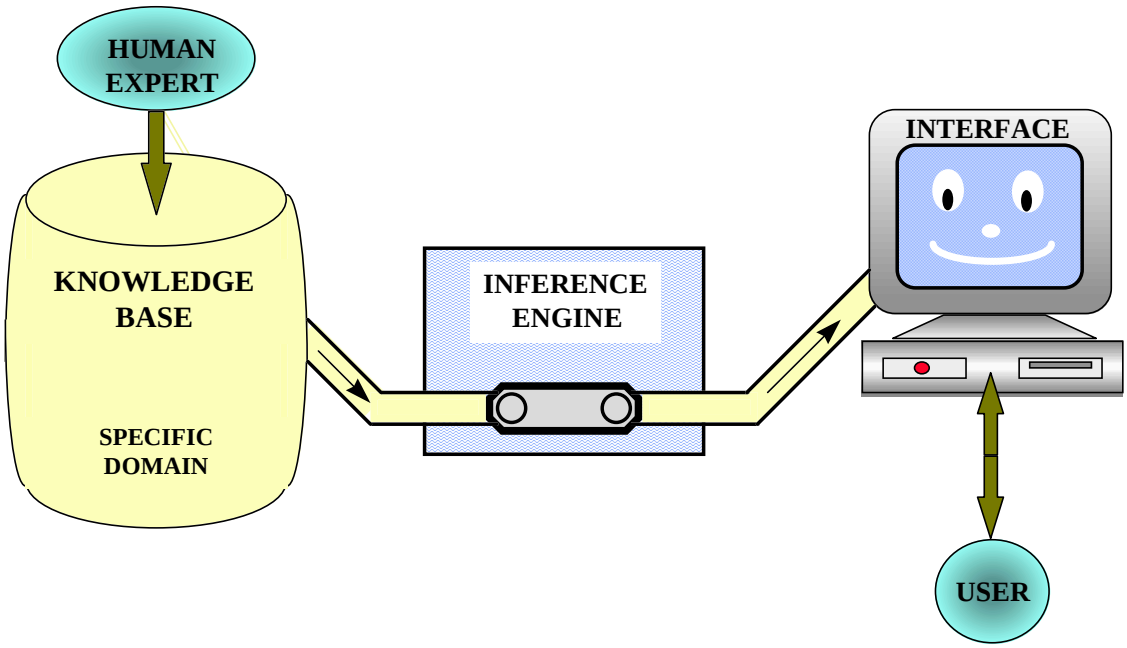

Figure 3 - Basic parts of a Knowledge Based System

In engineering in general and engineering education in particular, where computers are a natural tool of work for lecturers and students alike, a Knowledge Based System seems to be able to play an important role in so far as it combines two essential ingredients, providing not only advice but also the knowledge and information that underpin the advice given. Moreover, the knowledge and information are readily available and easily accessible in a Knowledge Based System application (which is not always the case in books and other sources). This makes a Knowledge Based System for consultancy about curriculum development particularly important for those involved with educational policy.

The Explanation Network

From the point of view of course developers it is important that the consultation should not only present suitable advice but also operate in a teaching-learning fashion, which is an important advance of this Knowledge Based System. Consequently, the tutorial aspect is regarded as a strength of this Knowledge Based System in so far as it not only replicates the expert but also offers additional explanatory knowledge and information to hand. Furthermore, it was recalled that very often course developers seeking expert advice would not feel entirely satisfied with the fact of merely answering questions and receiving a final prescription. On the contrary, the experience has demonstrated that course developers usually are very keen to know why particular questions are being asked and also on what basis the advice is being given.

As a result, an *Explanation Network* was devised and developed for this Knowledge Based System. It works in parallel with the main program as a system facility available for each question asked and advice given. As such, it consists of text frames with information, details and references about the relevant topic of the question and/or advice presented in the main program. Being in a parallel structure rather than in the main running consultation, the *Explanation Network* saves time for those users who do not need this assistance, yet it makes sure that it is available for those who do. The reason to implement such explanations was that the course developers using this Knowledge Base System would be accustomed to the screen as a natural environment for seeking the advice needed, therefore it would be an inconvenience to refer them to another source of explanations. Moreover, specialised books may not be available at the place of consultation.

Preliminary Results

Modular System at Huddersfield University

Since 1990 the University of Huddersfield, like many others United Kingdom institutions, has been implementing the Credit Accumulation and Transfer Scheme (CATS) and the Modular System approach was used to develop the principles and rules behind the whole process of course design. The reasons were that:

1. First and foremost, the modular structure is very flexible from the point of view of students since it allows them to build a course by accumulating credits from different modules which they can choose at will.
2. The Modular System allows for a quick up-dating of the course, given that current modules can be withdrawn and new modules can be offered without major changes in the structure of the course.
3. Due to the very intrinsic characteristics of modules, some form of recognition can be given to students who successfully complete a set of modules but do not meet the minimum requirements for a full degree.
4. For institutions which run several courses in engineering-based subjects, the Modular System also represents an economy of scale.

There are, however, some problems with the Modular System which must be addressed carefully whenever it is adopted. The major concern is the lack of coherence of the content and as a result, of the whole course due to student choice of optional modules. It was verified that if a very thorough system for planning and monitoring students' progress is not in place the coherence may be put at risk.

The Modular System would allow applicants with previous qualifications or credits (for modules) from other institutions to enter the course at points other than the start. Part-time students may also benefit from this Modular System by taking modules at their own pace. In this case, the length of the course is expected to be greater; however, their practical experience and previous qualifications (if any) should compensate for the Supervised Work Experience component of the course and even reduce the number of credits required to complete the course.

It was suggested that the structure of the course should comprise modules which would enhance the flexibility of the Credit Accumulation and Transfer Scheme. Therefore the most convenient type of module would be the Single Module, this would be a 15 week module, confined to one semester, and worth 10 credits. This module would have 75 hours of teaching/learning activities divided according to the peculiarities of each module (as discussed below). It was recognized that some parts of the content in engineering require more time to be delivered and could not be fragmented into Single Modules. Consequently, it was decided to have a choice of four types of modules, namely single, double, treble and quadruple modules with pro rata credit ratings. The total number of credits for each academic year was recommended to be 120 made up from the combination mentioned above. Therefore, the whole degree course would be worth 360 credits.

It was stated that the four major activities for learning content are Lectures, Tutorials, Practical/Project activities and Student self-study designated here as Unsupervised Work. These individual activities or combinations of them should therefore suit every module. It was clear from using the Knowledge Based System that the decision to allocate a particular module to one of these combinations was based mainly on the content of the module itself, its own nature with respect to practical or theoretical characteristics, the aims of the module and the resources available to offer it.

Another issue was to decide what would be the appropriate percentage of time to be allocated to each activity individually within a particular time-split for each module. It was identified that such a division of time would depend on three distinct parameters. First, the combination into which the particular module would fall. Second, the type of module being used (e.g. single, double etc.) Finally, the focus of the content of the module; that is, some modules concentrate on theory and principles, some on developing analytical skills, some on the practical aspects of the content and its applications, and others on methods and techniques of analysis and simulations.

An important concern was the advice issued by the Knowledge Based System regarding the integration of the content throughout the modules. It advised that this integration must be ensured both horizontally and vertically. The horizontal integration is to ensure that the modules in a given semester are of the same level. The vertical integration is to ensure that the transition from different levels, in different semesters, would represent a smooth continuity and overlapping of the content. In doing this it is important to realize that the principal guide is the development and achievement of the learning outcomes.

Curriculum Design for a New Electrical Engineering Degree Course at UFMG

In 1992 it was recognised by staff and students at UFMG that the curriculum in electrical engineering urgently needed revision. As a result a staff team was designated and spent considerable time developing new curriculum. Traditionally the methods used in Brazil for developing curriculum had used the Piecemeal Approach. This was not the case at UFMG as the process began by making a diagnosis of the situation, highlighting the problems and analysing solutions found by others at home and abroad. They tried to follow a systematic approach and produced a full curriculum document in 1994 which was nevertheless rejected by other members of staff.

One year later another committee was set up for the same purpose and was responsible for producing a coherent curriculum which would be acceptable by most. This time the Systematic Planning Approach was adopted from the beginning. The aim of the curriculum was stated as well as its goals which were thoroughly written. Despite the fact that all the committee members were aware of the approach being followed, due to the lack of experience, some were not convinced that all the goals should be pursued and considered turning to the traditional way of designing curricula.

According to the experience at UFMG a persistent and enthusiastic leadership is very important. Occasionally lecturers find it difficult to follow an innovative way of performing a task such as designing new curricula. The Knowledge Based System has been an important and permanent source of consultation and on many occasions it has helped members of the committee and staff to improve their comprehension of how to write Learning Outcome Statements.

In order to be able to fulfil all the goals intended by the new curriculum it became clear that the better option available in terms of the pedagogical approach was that based on Learning Outcomes. This is because of the many advantages this approach provides, among others, in terms of the possibility of checking the learning process and pointing out clear directions for the

staff and students. As a result of that a conclusion was reached, namely that the existent course structure at the electrical engineering degree course at UFMG was not the best available. An unwanted feature of its structure was its fragmented nature. It is was also strict and did not allow much choice for the students.

Conversely, in the modular structure adopted each course unit is a discrete set of Learning Outcomes, which most of the time has no prerequisites. This is a big advantage given that the students (supervised by a tutor) can decide which pathway is more convenient for them according to their background and interest. The number of credits assigned to any individual unit is variable and depends upon its Learning Outcomes. Credits are related to the student progress towards the degree, the assessment strategy and the course pattern.

The Learning Outcomes were identified based on the intended goals of the curriculum and in consultation with employers in industry, professional bodies and the University staff. This exercise, based on a modified DACUM Technique (Finch, 1979), has produced a lot of data which is being used also to define what is named the Course Pattern. The consultation with industry (employers and professionals) was a very difficult task. It is fair to say that the most useful contribution came from some senior consultants, while other employers were still thinking in terms of old-style engineering graduates. Several meetings were carried out with the University staff in order to explain to them the whole curriculum design process. Unlike the previous experiences, this time they were very receptive and collaborative this being an important point. Curriculum changes (in the traditional way) had long been expected and postponed and this had caused some sort of anxiety among the staff and students. In order to overcome this problem meetings were organized with both groups, the students still needing to improve their participation.

The work of writing the Learning Outcomes was divided among the committee members. Due to the fact that most members were more familiar with the so called Specific Outcomes (those related to specific subject), these outcomes were split into four subject groups including engineering design (which had been overlooked). The Core Learning Outcomes (related to the general goals) and the General Outcomes (related to general abilities) were easily written. Once staff start discussing the purpose of what they have been doing and with very clear directions from the committee this comes as a natural exercise. The committee has thus managed to grasp the principles of Learning Outcomes and brought other staff members to join the curriculum design process. This methodology has been proving to be successful, yet great care must be taken otherwise staff members tend to focus on the subject content. The work is not yet finished and currently the committee is working towards the Course Pattern.

Learning Outcomes approach at FUNREI

For two years (1995/96) some course units in the electrical engineering degree course at FUNREI have been using the Learning Outcomes approach. Moreover, lecturers have changed the pedagogical approach innovating on the teaching/learning strategies by adopting more student-centered activities. Following the methodology suggested by the Knowledge Based System, particularly the link between Learning Outcomes, Scheme of Assessment and Teaching/Learning

Strategies shown on the diagram of figure 2, these units were redesigned. Despite the fact that this change is seen as a Piecemeal planning, given that other units are still being delivered in the old style, the objective was to demonstrate whether or not the Learning Outcomes approach could improve students' achievement.

The results have been encouraging and can be measured in two different ways. One is the statistical data which has demonstrated that students' pass rate in these course units has increased to 50% yet it is still low for international standards (these data should be analysed within the Brazilian context). The other result is the students' positive response to a survey in which they could anonymously assess aspects of the units delivered on a Learning Outcomes basis. It can also be inferred from this experience that the students are better prepared since their performance in other course units (which depend on the knowledge, skills and attitudes developed on those based on Learning Outcomes) has also improved. The students request at present is to redesign the whole engineering degree course in order to incorporate this new approach. At the moment, a curriculum modernization project is being developed and the outlines have already been approved at the Graduate Academic Board level and should be carried out in 1997/98 for all degree courses at FUNREI.

Conclusion

This paper argued that in order to face adequately the challenges posed now and in the future to engineering it is necessary that policy makers in education devise alternatives appropriate to the scenario of the next century. The paper demonstrated that a Knowledge Based System for Curriculum Development can represent one of these alternatives by (a) Making available an Intelligent Software Package which contains a comprehensive knowledge base in curriculum design and (b) Developing a tool for training in curriculum principles and concepts using a tutorial element which is a low cost vehicle of disseminating expertise.

A relevant feature of this Knowledge Based System is that it is user-friendly which means that course developers do not need to know how the system was built or to know any computer language in order to run a consultation and interact with the system. It is also stressed that this System has the capacity to cater for flexibility and new forms of course delivery that are being developed for the next century such as multimedia material and interconnected terminals to deliver courses at home or at the work place.

The paper also tried to emphasize that modern curriculum development has to embody the new paradigms discussed. The novelty of the present work is that it incorporates a close investigation of these new principles and concepts in a practical way and uses a rule-based system in a systematically planned approach to curriculum development. The writing of intelligent practical rules, which organize and represent the factual and expert knowledge in this field, bridges the existing knowledge gap between theory and practice. The preliminary results achieved by using this approach at the universities mentioned are encouraging.

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