DOCUMENT RESUME

ED 443 728 SE 063 994

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TITLE	Intelligent Course Structure--A Framework for Improving the Pedagogical Approach in Engineering Education.
PUB DATE	1998-08-00
NOTE	9p.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	*Curriculum Design; Educational Change; *Educational Improvement; *Educational Needs; *Engineering Education; Higher Education; Instructional Effectiveness; Professional Development

ABSTRACT

This paper outlines the role that an innovative technology can play in assisting course designers in the development of new curricula aimed at engineering degree courses. A Knowledge Based System (KBS) which embodies expertise in course design is described. The KBS described gives advice on curriculum development concepts, principles, and techniques rather than specific course content. Tests have shown that this KBS has particular relevance to those course designers who have content experience but lack curriculum design expertise. (Author/WRM)

INTELLIGENT COURSE STRUCTURE – A FRAMEWORK FOR IMPROVING THE PEDAGOGICAL APPROACH IN ENGINEERING EDUCATION

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ABSTRACT *- This paper outlines the role that an innovative technology can play in assisting course designers in the development of new curricula aimed at engineering degree courses. A Knowledge Based System (KBS) is described in which expertise in course design is embodied and how this can form a partnership with the course development team. The KBS described gives advice on curriculum development concepts, principles and techniques rather than specific course content. Consequently it has flexibility and adaptability enabling it to cater for specific institutional needs and course objectives. Emphasis is given to course structure and how the KBS assists the course team in the task of designing the units of study which foster both a student-centred and an achievement-led approach. Tests have shown that this KBS has particular relevance to those course designers who have content experience but lack curriculum design expertise.*

1. INTRODUCTION

Engineering education has been evolving relentlessly and more recently under vigorous economic pressures, namely budgetary constraints. On the other hand, the new world economic order and the escalating competitiveness among countries have called out for a multiskilled and better trained engineers. Moreover, the engineers of the next century will face a challenging world which requires a fully prepared professional regarding knowledge, abilities and attitudes. Educationists have responded to these challenges by coming up with new proposals for education, such as the ones from the REENGE project [1]. These initiatives primarily aim at striking a balance between efficiency and effectiveness in developing and running new courses. As a consequence, course designers have faced a huge task when developing new courses (or when updating existing ones) to make these courses 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 has brought about an awareness of the need to improve the pedagogical approach in engineering education where the course structure plays a crucial role.

This paper addresses these issues by describing an innovative methodology of designing course structure. It advocates that by using a knowledge based system it is possible to achieve a more effective and manageable course structure which favours course delivery. The knowledge based system gives advice about the appropriate time to be allocated to teaching/learning activities to determine the balance between the volume of material delivered and the workload of students and staff. Not only does it improve the way of designing the course units but, more importantly, it fosters a pedagogical approach which is both, student-centred and achievement-led. There are four levels in the framework, ranging from a teacher-centred to a student-centred approach all of them assuming forty hours of study time a week, from students point of view. The system starts by identifying the institutional experience in course structure and suggesting the appropriate design for course units, in terms of student-staff contact hours, unsupervised work hours and free time study hours. At the same time it invites the course designer to move to a new level reducing student-staff contact hours. It is thus assumed that, in this framework, students are able to and should construct their own knowledge and expertise in engineering by playing an active role in the learning process. In this way the knowledge based system assists in implementing change.

Engineering curricula nowadays require a multidisciplinary approach to cover the wide range of factors impacting on technology, education and society. The flexibility of the framework proposed 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 work is that it encourages the course designer to move a step forward in developing a course delivery which recognises the needs of the future world scenario in engineering. The methodology proposed by this framework raises the idea of content integration (horizontally and vertically), which is suggested to be carried out in a systematic planning approach, avoiding the less desirable fragmented approach of course design. Current engineering degree courses have been criticised for both being fragmented and lacking coherence. The paper therefore discusses how the knowledge based system gives advice on the vertical and horizontal integration of the course content together with the overall coherence of the new curriculum. The authors advocate that by connecting engineering course units and other subjects traditionally delivered as separate entities, students can have a more holistic understanding of their course and the meaning of engineering.

Furthermore, the use of a knowledge based system allows the course designer to be educated in the philosophy underpinning the advice given and prepares them for future curriculum development exercises. This is particularly useful for engineering educators who have limited experience of curriculum development and may only have specialist subject content expertise. This Intelligent Course Structure has already been successfully tested as a research tool and the principles behind the developed system have been implemented in United Kingdom and Brazilian Institutions.

2. METHODOLOGY

A knowledge based system is a branch of artificial intelligence within the general area of "Problem-Solving" and has been considered the most successful application of artificial intelligence [2]. The development of a knowledge based system is a task performed by a knowledge engineer who is responsible for acquiring and representing knowledge and expertise in a particular field of knowledge - domain. The authors have developed a knowledge based system in the domain of curriculum development named INCUDE, an acronym for Intelligent Curriculum Designer [3]. One of the subdomains of INCUDE, namely *Course Structure*, was selected to be described in this paper, given that it is strongly connected with the effective implementation of the advocated pedagogical approach which is student-centred and achievement-led. The development of the subdomain *Course Structure* required several knowledge elicitation techniques in order for the expert to address the major topics within this subdomain. Having addressed these topics the knowledge and expertise were coded in a prototype which was used to refine the eventual knowledge based system. This prototype has been refined in order to accommodate the flexibility of allowing for different levels of student activities, which is the focus of this article.

3. KNOWLEDGE AND EXPERTISE

A list of concepts relevant to *Course Structure* is presented (in alphabetical order) in table 1. These concepts and their definitions are embodied in the knowledge based system. They are considered essential for an understanding of the whole framework developed for this subdomain. Consequently, they are either displayed throughout the consultation (in the main program) or they can be accessed through a parallel structure named *Explanation Network* [4] which were devised to give extra assistance for those course designers who wish to learn more about a particular concept.

Table 1 - Concepts in Course Structure

Academic Qualifications	Credits	Prerequisites
Accreditation/Validation	Entry Requirements	Progression System
Attendance Pattern	Learning Activities	Required Standard
Contact hours (student-staff)	Learning Experience	Scheme for a Course
Content Integration	Modular System	Supervised Work Experience
Course Pattern	Modules	Timetable
Course Structure	Pathways	Unsupervised Work hours

An initial concern is to characterise what is meant by the structure of a course and Structure was defined in the knowledge based system as the framework in which a certain body of knowledge is imparted in a specific subject area (discipline), designed to lead students to a recognised award. The structure of a course should define the breadth and depth of material to be delivered (within time limits) as the means by which students would undergo a global learning experience that would equip and qualify them to play the role of engineers. A structure is required if any course is to have recognition nationally and internationally. This is a way of establishing that educational standards in different institutions are comparable.

3.1 The Modular System

There are different ways of designing the structure of a course. It could be, for example, structured around Single Units, or Subjects, or Grouped Units. However, the knowledge based system uses the Modular System to develop the principles and rules behind the whole process of course design and to demonstrate their application. 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 hours of study (or credits) from different modules which they

can choose at will. This is well-known in the United Kingdom as the Credit Accumulation and Transfer Scheme (CATS). Yet, in disciplines such as engineering, which has a structured content organised in a linear pattern, choices must be coherently organised.

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. This facilitates course evaluation and review, and these can be carried out more often.
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. This is because a module is a self-contained unit of study; it is defined by the learning outcomes to be achieved by the student, the notional amount of time allocated to it (or the number of credit points it carries) and its associated scheme of assessment [5].
4. For institutions which run several courses in engineering, the Modular System also represents an economy of scale with the optimum use of time, materials and resources (since modules which are common to different courses may be offered to a larger number of students at the same time).

It can be observed that the third reason cited above actually suggests a hierarchical award system such as a Certificate in Higher Education, a Diploma in Higher Education, and Degree. This award system has been foreseen by the new Brazilian education legislation (LDB) namely *Sequential Courses in Higher Education*. The system could be put in place by meeting certain minimum conditions for each award (that is, stipulating the specific number of modules or number of credits necessary for each award). It would recognise students' effort and time dedicated to higher education even though, for some reason, they have to leave the system before achieving the full Degree.

There are, however, some problems with the Modular System which must be addressed carefully if it is going to be adopted. The major concern is the lack of coherence of the content and, as a result, of the whole course. This is caused by the fact that modules may be undertaken at students' will, making it difficult to ensure an appropriate sequence and a coherence in their programmes of study. The knowledge based system warns that if a very thorough system for planning and monitoring students' progress is not in place the coherence may be put at risk. It is also advised that the scheme for assessing the students performance should be based on the demonstration of learning outcomes, that is, what the students have really achieved after having undergone a learning experience [6]. These requirements, therefore, play an important part in ensuring that flexibility is granted without jeopardising course coherence. It is suggested that each student should have a tutor who would make sure that the student choice is consistent. In the Brazilian case this problem has been overcome to some extent by the curriculum directives which is being defined by the National Council for Education through an institutional survey.

The Modular System would allow applicants with previous qualifications or credits from other institutions to enter the course at points other than the start, thus making the length of the course shorter. Part-time students (i.e. those who work in the engineering field) 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 modules or credits required to complete the course.

3.2 Modules Specification

The knowledge based system suggests that the structure of the course should comprise modules which would enhance the flexibility of the engineering curriculum. Therefore the most convenient type of module would be the Single Module, this would be a 15 week module, confined to one semester. This module would have 75 hours of teaching/learning activities divided according to the peculiarities of each module (as discussed in subsection 3.3). However, it is recognised 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 initially suggested that the structure to be designed using this knowledge based system would have available for course designers the choice of four types of modules:

- Single Modules = 75 hours over 15 weeks, in one semester;
- Double Modules A = 150 hours over 30 weeks, in the academic year;
- Double Modules B = 150 hours over 15 weeks, in one semester;
- Quadruple Modules = 300 hours over 30 weeks, in the academic year.

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 as described in section 4, and for each year it is possible to have fifty different combinations. It is not educationally recommended for courses in engineering to spread the content of a module over a period of time longer than an academic year (that is, 30 weeks) and neither would it be educationally sound to concentrate a module in less than 15 weeks. The total time for each academic year was recommended to be 900 hours of teaching/learning activities (for example, 12 modules per year with 75 study hours per module). It most be emphasised that this time does not represent student-staff contact hours only, it is the total time engineering students should dedicated to their studies including student-staff and unsupervised work. On top of that, other 10 hours a week – named free time study - should be dedicated to complementary courses such as languages. That would add up around 40 hours of study a week. This initial recommendation of 900 hours a year eventually become the Level 1 in the proposed framework which, at present, consists of four level as described in section 5.

3.3 Teaching/Learning Activities per Modules

The knowledge based system states that the four major activities for learning engineering are Lectures, Tutorials, Practical activities and Student self-study designated here as Unsupervised Work. These individual activities or combinations of them should therefore suit every module. These activities were classified by the knowledge based system into six categories shown below. Other combinations were then regarded as not suitable for engineering courses.

- Category CA - 1 = Lecture, Tutorial, Practical and Unsupervised Work;
- Category CA - 2 = Lecture, Tutorial and Unsupervised Work;
- Category CA - 3 = Lecture, Practical and Unsupervised Work;
- Category CA - 4 = Tutorial, Practical and Unsupervised Work;
- Category CA - 5 = Tutorial and Unsupervised Work;
- Category CA - 6 = Practical and Unsupervised Work.

The decision to allocate a particular module to one of the above categories is based mainly on the content of the module itself (group of learning outcomes), its own nature with respect to practical or theoretical characteristics, the aims of the module and the resources available to offer such a module. The combination of these and other variables was implemented in a set of rules devised to reflect the expertise in this topic and to assist course designers in similar tasks. The implementation of this set of rules is discussed in section 4.

Having defined the above categories, the next step 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 category into which the module being analysed would fall. Second, the type of module being used (for example, Single Module, Double Module and so on) as this defines the limits of time in a week. 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. The rules, which would relate these parameters to one another (in order to lead the course developer to a solution compatible with the inputs made), are discussed in the next section and are implemented in the knowledge based system.

An important concern investigated in this subdomain was the advice that should be issued by knowledge based system regarding the integration of the content throughout the modules. It is advised that this integration must be ensured both horizontally and vertically. The horizontal integration is to ensure that (for each semester of the structure) the modules which are of the same level (for example, advanced level) would cover all the essential aspects of the content allocated to that level, in an integrative way. The vertical integration is to ensure that the transition from different levels, in different semesters (or year), would represent a smooth continuity and overlapping of the content. The Staff Team should make sure that the modules are not written in isolation and should look at these two dimensions of integration (that is, the horizontal and vertical). The advice is to check the modules in successive iterations in two instances. Firstly, having finished the process of writing the modules, the module writer together with the Staff Team would check completeness, amount of material, level of content and connections between and across other modules. Secondly, the Staff Team and the department/school panel would examine issues such as the timing of material, the prerequisites and the standard of the modules (for example, if the modules are at the same standard regarding the content and the scheme of assessment).

4. IMPLEMENTATION AND VERIFICATION

The knowledge and expertise discussed in section 3 is implemented in an Expert System Shell as a prototype which was used for both probing and testing purposes, in accordance with the overall methodology [4]. Following the usual procedure, some basic concepts concerning the design of the structure of the course were embodied in a few opening text frames which are displayed to the course developer before the interaction takes place. This is to give the course developer the minimum information required to run the consultation. Extra information and related knowledge can be accessed by using the *Explanation Network* facility available in the knowledge based system.

4.1 The Implementation of the Study Hours Section

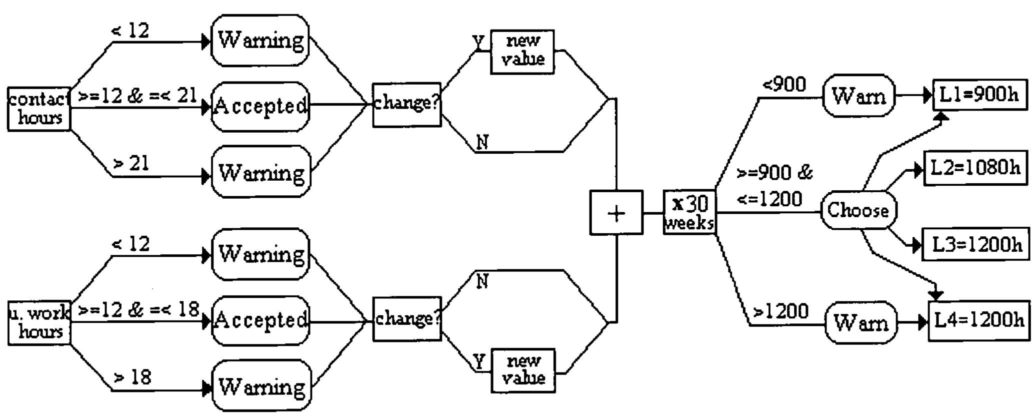
The rules which define the minimum and maximum limits of time spent on teaching/learning activities in a week and consequently in a year, were implemented through the limits of tutor contact hours (between lecturers and students) and unsupervised work hours (students' own time for studies). The individual limits for an engineering course were established as being:

a) Staff-student Contact Hours:
Minimum of 12 hours a week,
Maximum of 21 hours a week.

b) Unsupervised Work Hours:
Minimum of 12 hours a week,
Maximum of 18 hours a week.

The combined limits should therefore suggest that the total study time that the students should spend in a week would be a minimum of 24 hours and a maximum of 39 hours. However, it was realised that the combined 39 hours of study in a week would be a limit too high given the economic implications and, more importantly, the excessive workload on students and staff. However, in order to suit some institutions, where a strong teacher-centred approach is adopted, and cover a wide range of possibilities, this alternative was also incorporated in the knowledge based system as level 4 (i.e. 1200 hours of activities a year = 40h/w x 30weeks).

The interaction takes place when the designer is invited to type in the number of hours that has been planned for these two items above and depending on the input provided by the course developer different advice is displayed. This can be seen in figure 1 which also shows that after having displayed the advice, the knowledge based system allows the course developer to change the figures initially input. This change may be motivated by the advice displayed as a result of the figures input by the course developer which, initially, might not have been within the limits suggested by the knowledge based system. After this new interaction the knowledge based system works out the final amount of time for the whole academic year and, again, different advice is displayed depending on the final result calculated by the system.



KEY: a) contact hours = Number of Student-staff contact hours per week
b) u. work hours = Unsupervised Work (number of hours per week)
c) L1, L2, L3, L4 = Levels of the framework related to total time of activities a year

Figure 1. Rules for the total time for Teaching/Learning Activities

Regarding the total amount of time, the advice is that it should be within the limits of 900 and 1200 hours of teaching/learning activities in an academic year. Therefore, the eventual version of this set of rules was refined in such a way that when the course designer's figures are within the individual limits but their combination exceeds the total limit in a year a warning is issued in order to draw the attention of the course developer to this problem.

The most important point being that if the level reached by the course developer is L4, L3 or L2 the knowledge based system invites the course developer to change level moving to the next one which always suggests a reduction on the student-staff contact hours. This would transfer to students the responsibility for their own learning process, striving to construct their knowledge, developing their abilities and at the same time changing their attitude to face the new requirements and challenges that the engineer of the next century will face.

4.2 The Implementation of the Module Specification and Time-split Sections

The next step in the implementation of this subdomain was to represent the rules which would lead the course developer to define the combination of modules available in this system (see 3.2) that would best suit their needs. The idea was to exploit the maximum number of combinations possible within the choices available, taking into account the total time suggested for a year (L1=900 hours). As a result of that, in the initial prototype a decision tree representing the 50 possible options was implemented in the knowledge based system. After the refinements discussed in section 5, the present *Course Structure* subdomain has four decision trees each of them with different combinations (i.e. L1 - L2 have 50 options and L3 - L4 have 41 possibilities of arranging each year of the curriculum).

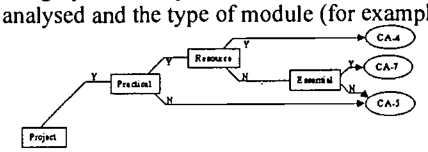
An example of the rules for the section of the knowledge based system devised to identify the category of teaching/learning activities which would suit each module can be seen in figure 2. This section was implemented in order to assist the course developer in allocating the module being analysed to one of the six categories described in section 3.3. The course developer should supply the information related to each variable represented in this decision tree in order to receive advice on the category that best suits a particular module.

The implementation of this set of rules required that an extra category (Category 7) had to be represented to take account of the fact the some advice should be displayed even when the course developer could not meet the requirements for any of the other six categories. This may happen when the variable *Resource*, which in some cases may be considered essential for certain teaching/learning activities, is not addressed. This means that, when enough resources are not available to allow the teaching/learning activity to take place, the advice is to consider seriously the possibility of not offering that module in that institution.

a Single Module) have been identified, the input of the course designer relating to the nature of the content (focusing on theory, practice and so on) would be enough for the knowledge based system to reach the goal of this section, the time-split for that particular module.

It is very important to stress that the *Explanation Network* has been implemented for all the sections of the knowledge based system described above. The *Explanation Network* has relevant information and help for the questions that are asked

The next step was to implement the division of the time (planned for a particular module) amongst the teaching/learning activities identified as needed for the delivery of that module. Part of the decision tree for time-split (an example for Category 1), can be seen in figure 3. The rules in this decision tree use the suggested 900 hours a year (or 30 hours a week) as the total amount of time for the teaching/learning activities planned. The decision tree is different for each level of the framework. The eventual goal of this section is to allocate the advisable amount of time to each teaching/learning activity for a particular module. The rules were implemented in such a way that this goal is reached as follows. Since both the category of activity for the module being analysed and the type of module (for example,



to the course developer. This tailors the User Interface to the course designer's needs and provides extra assistance in tackling the relevant issues.

KEY: a) CA – X = Category of Activities as stated in item 3.3
b) Project = Is this a *project* module?
c) Practical = Does the delivery of the module require *practical* work?
d) Resource = Does the institution have the practical *resources* required to deliver the module?
e) Essential = Is the practical work *essential* for the module?

Figure 2. Part of the Decision Tree for Categories of Teaching/Learning Activities

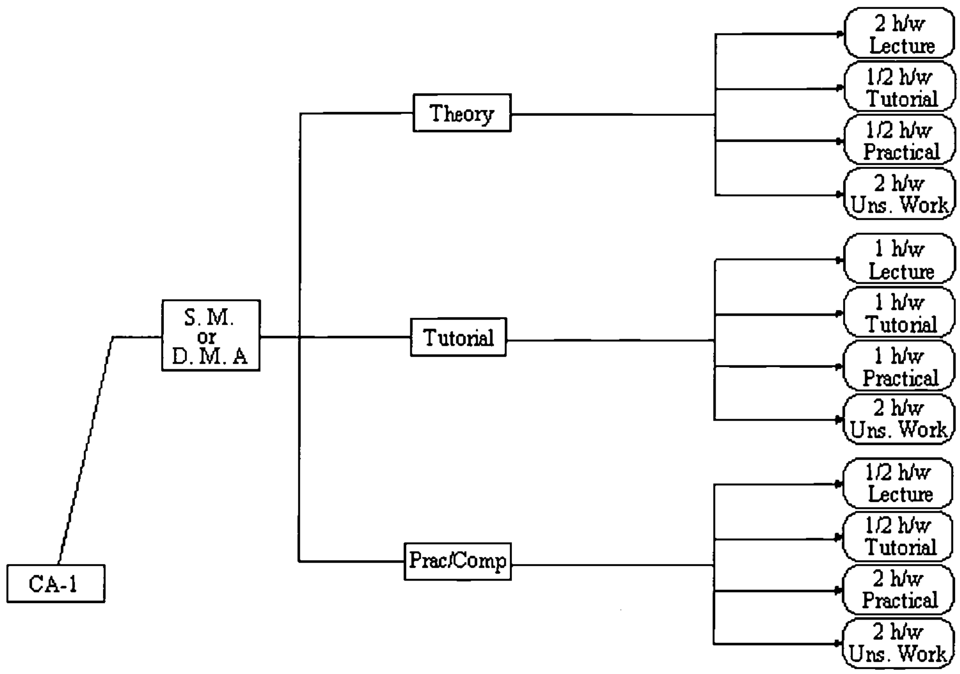


Figure 3. Part of the Decision Tree for Time-split - An example for Category 1

5. TESTING AND REFINEMENTS

The subdomain *Course Structure* of the knowledge based system was successfully tested for Verification, Validation and Acceptability as indicated by the overall methodology [4]. It was then put in practice in Brazilian universities when it was verified that some courses would need to start with a 1200 hours of teaching/learning activities a year in order to address their own experience and background. It was verified that, although the principles and concepts would fit any institution, the knowledge based system lacked flexibility to meet different institutions requirements. The conclusions which resulted of this implementation test were welcome by the authors for two reasons:

a) it would improve the knowledge based system flexibility since, up to then, the option was only a structure with 900 hours a year and

b) allow the course designers in different institutions to move smoothly from a more teacher-centred to a student-centred approach without breaking the current experience.

From this experience the authors decide to improve the subdomain *Course Structure* by implementing a four level framework as presented in table 2. This would not only allow for different alternatives of teaching/learning time allocation in order to suit different institutions .but, more importantly, it would invite the course designer to move to a upper level (for example: from level 3 to level 2) which would be a step forward in the direction of a student-centred approach.

The experience has demonstrated that, as a result of this change in the structure of the engineering degree courses, the staff team in engineering education have being encouraged to redesign their teaching/learning strategies in order to meet this student-centred approach leading to new experiments which motivates the students to play an active role in becoming engineers. Moreover, schemes of assessment have been focusing on what the students have really achieved by demonstrating a group of learning outcomes rather than memorising content. This pedagogical approach has also echoed in the engineering education in America through the ABET – Engineering Criteria 2000 [7].

Table 2 – Level of the Framework

Level of the framework	Student-staff contact hours (weekly)	Unsupervised work hours (weekly)	Free time study hours (weekly)	Total time of activities (yearly)
L 1	18	12	10	900
L 2	24	12	4	1080
L 3	30	10	-	1200
L 4	40	-	-	1200

6. CONCLUSION

This paper presents the findings of the investigation carried out in the development of a knowledge based system (KBS) devised to give assistance in the design of curricula for engineering degree courses. The subdomain *Course Structure*, described in this paper, gives advice on how to define and design the structure of an engineering course taking into account the needs to foster a student-centred and an achievement-led approach. The knowledge and expertise acquired were represented and coded into a computer package (INCUDE) which is portable and user friendly. The flexibility of the system has been improved by the refinements made incorporating different levels of learning activities which widened the system applicability to suit institutions with different contexts. Tests were encouraging and reinforced the idea that a knowledge based system to assist course teams in designing and defining the structure of engineering courses is of great value particularly for institutions where this kind of expertise is rather limited.

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