



Title	Design of the curriculum for a second-cycle course in civil engineering in the context of the Bologna framework
Authors(s)	Gavin, Kenneth
Publication date	2010-02-17
Publication information	Gavin, Kenneth. "Design of the Curriculum for a Second-Cycle Course in Civil Engineering in the Context of the Bologna Framework." Taylor and Francis, February 17, 2010. https://doi.org/10.1080/03043790903511086 .
Publisher	Taylor and Francis
Item record/more information	http://hdl.handle.net/10197/4101
Publisher's statement	This is an electronic version of an article published in European Journal of Engineering Education, 35 (2) 2010-05, pp.175-185. European Journal of Engineering Education is available online at: http://www.tandfonline.com/doi/abs/10.1080/03043790903511086
Publisher's version (DOI)	10.1080/03043790903511086

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Design of the curriculum for a second-cycle course in civil engineering in the context of the Bologna framework

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(Received)

Abstract:

This paper describes the design of the curriculum for a ME programme in civil engineering at University College Dublin (UCD). The revised programme was established to meet the requirements of the Bologna process and this paper specifically considers the design of a new, second-cycle master's component of the programme. In addition to considering the content required to meet the learning outcome specified by the professional accreditation body, the paper presents details of attempts to move from a traditional instructor centred model to a student centred model of education in order to promote reflective (deep) learning. Although the paper presents a model curriculum for a civil engineering programme, the holistic approach to curriculum design outlined, which considers the organisation, sequence and evaluation strategies adopted is applicable to all subjects' areas in higher education.

Keywords: curriculum, Bologna process, reflective learning, civil engineering

1 Introduction

Traditionally the models of Engineering Education in Continental Europe have differed substantially from those in the UK and Ireland. In the former, a hierarchy of long-cycle bachelor degree programmes which are a minimum of five years duration and short-cycle three to four year diploma programmes coexist (Maffioli and Augusti 2003). The Anglo-Saxon model (followed in the UK and Ireland) although of shorter duration than the long-cycle continental European model, is more content focussed and to date has resulted in the award of a bachelor degree after four years in Ireland.

The Bologna process, initiated in 1999 with the Bologna declaration, is a project to create a European Higher Education Area (EHEA) with a comparable system of academic standards and quality (Clark and Olabi 2008 and Heitmann 2005). The main objectives of the process are: (i) to increase mobility of staff and students within the EHEA, enhance the attractiveness of the EHEA as a destination for non-EU students and to ensure a quality education and knowledge base for the development of the EU. In order to achieve the first objective, in the light of substantial differences between the educational models followed across Europe a basic framework of a two-cycle – bachelor followed by masters model with a system of European Credit Transfer System (ECTS) assigned to each stage was developed. Ireland is a signatory to the Bologna Treaty and Engineers Ireland, the professional body of Irish Engineers, has raised their minimum requirement for ordinary membership from an honours bachelor's degree to a master's degree from 2013 onwards. Since ordinary membership is a step on the standard route to chartered status, which is a requirement for most senior positions in industry, there is general agreement that a master's level

degree will become the standard educational achievement of most future civil engineers, thus necessitating a redesign of the Engineering curriculum.

This paper describes the design of the curriculum for a new Master of Civil Engineering (ME) degree programme at University College Dublin (UCD). The format of the two-stage cycle (see Hedberg 2003) adopted by the engineering schools at UCD is a 3 + 2 model, where a 3 year Bachelor of Science (BSc). is followed by a 2 year ME. In particular it considers the international context for the development of the curriculum and informing the addition of material afforded by the extension of the course from 4 to 5 years. Whilst this in itself is a topical area of discussion for those involved in engineering education, the paper presents a holistic approach to curriculum design which is applicable to any subject area. The entire process is considered from choice of the educational model underpinning the curriculum design, through to the organisation and sequencing of the programme and finally the evaluation strategies adopted to best ensure that the learning outcomes are achieved.

2 Need for an Updated Curriculum

International Debate regarding Engineering Curricula

There is considerable international debate about engineering education which should be used as a context for those involved in updating existing programmes and designing new courses (Lenschow 1998, Ditcher 2001 and others). Based on the results of surveys conducted with graduate employers Miller and Olds (1994) and Lang et al. (1999) suggest that theoretical knowledge is just one of a number of attributes required by graduates which include: communication skills, an ability to

work in small teams, ability to self educate, an ability to consider non-technical constraints and the ability to work in multi-disciplinary teams.

An additional fundamental skill which many employers view as essential is an ability to design components and systems. There is general agreement that whilst Universities are well equipped to teach analytical skills, design which should form the backbone of the training of an Engineer, is often poorly treated. Waks (2001) in a review of earlier works by Schon (1983, 1987) notes that the philosophy of the research University results in a normative professional education curriculum in which students first study basic science, then applied science, and at a later stage in the course applying this science to practical problems. Since complex real-life problems encountered in practice do not lend themselves to such neat distinctions between theory and practice, graduates can be poorly prepared to solve these. The implication is that some attempt to integrate design and theory be developed. An additional factor identified by Dym (2003) cites the nature of the scientific research model of engineering (and indeed most branches of) higher education, as being a reason that design is poorly treated. Given that staff promotion depends largely on the quantity of research publications, numbers of PhD students graduated and research grant income generated; many University teachers have little or no practical design experience, having spent most if not all of their careers studying, researching and teaching at Universities as periods spent in industry would have a detrimental effect on their research output.

In recognition of the need to overcome some of the perceived deficiencies in the education of Engineers, a number of professional engineering and accreditation

bodies such as the United States Accreditation Board for Engineering and Technology (ABET) have established task forces to consider the curriculum of engineering programmes. In Europe the implementation of the Bologna process is occurring in tandem with an investigation of the practice and development of civil engineering curricula through European higher education has been undertaken as part of the Erasmus component of the SOCRATES programme through a thematic network project, European Civil Engineering Education and Training (EUCEET). In an attempt to ensure that the EHEA becomes a reality, the EUCEET members formed a collaborative grouping with the Tuning Educational Structures in Europe (Tuning Project) to compile a comprehensive (and sizeable) list of competencies (outcomes) for civil engineering graduates. In the United States, the American Society of Civil Engineers (ASCE) completed a similar exercise, identifying fifteen outcomes, defined as a Body of Knowledge (BOK). Sanchez-Villa et al. (2006) noted the similarities between the outcomes defined by both bodies with many being identical. This is to be expected as reviews of many higher education programmes suggest a relatively generic list of competencies results, (See Table 1).

Majewski (2006) reported on the core curriculum which should be followed on a civil engineering course designed to match the outcomes determined by the EUCEET working group. Whilst noting that planning any curriculum involves consideration of: (i) what should be taught, (ii) how should it be taught and learned and (iii) who should teach and learn it, they defined what they term a *core curriculum* which should be universal. Similarly Meyer and Jacobs (2000) describe the development of a new Civil Engineering curriculum to meet ABET's revised criteria.

In many such reviews outcomes and content are described however no account is reported of the method of delivery or assessment of the curriculum.

Educational Philosophy

Ramsden (1992) identifies a pervasive feeling developing amongst higher education lecturers that students exhibit poor knowledge retention capabilities, yet display the ability to pass exams whilst simultaneously having developed a poor understanding of basic principles and concepts. Students may approach learning in one of two ways; surface and deep approaches (Marton and Saljo 1976). In the former, facts are treated as unrelated and are stored as discrete information. In the latter, the facts are considered in the context of existing knowledge and the student considers their underlying meaning. Unsurprisingly, students who undertake deep learning generally exhibit much better learning outcomes. Whilst some students who are unengaged will follow a surface approach to learning, most will (if engaged) adopt deep approaches.

A first step in the redesign of the curriculum for many professional programmes professional consists of an exercise in mapping specified learning outcomes to existing content. Whilst attempting to improve the outcomes obtained, such a narrow focus of the term curriculum evident in these attempts to implement outcomes based education, results in a product based curriculum model (Fraser and Bosanquet 2006). The product model described by Neary (2003), see Figure 1 is one where the teacher takes primary responsibility to transfer the content to the student. The product model will result from curriculum design which focuses on content and

outcomes. Knight (2001) notes that outcomes led curriculum planning is problematic and success will be achieved through consideration of coherence through the entire structure which is created through attention to processes, messages and the quality of connections and the environment. An alternative approach is the Process model (see Figure 2) which has been adopted in this review is one where the hierarchy is reversed. In this model significant attention is afforded to teaching and learning methods and assessment procedures, and the student takes control of their learning, thus facilitating the adoption of deep (reflective) learning by students.

3 Curriculum for new Civil Engineering ME Programme at UCD

Programme Goals

The first step in the design or planning of a new curriculum is to establish goals for the programme. The new ME course in civil engineering at UCD will:

1. Produce graduates with specialist knowledge in the area of Structural or Water Engineering
2. Develop future leaders of the civil engineering profession by developing complimentary skills in the area of business, law and professional practice
3. Develop links with industry to facilitate a multi-disciplinary, project oriented learning environment

To achieve these goals it will be necessary to match the learning outcomes (which are now almost universally accepted (See Table 1) to the curriculum design.

Having considered the curriculum model to be adopted, it is essential to consider first the content and organisation and then the evaluation strategies to be followed.

Course Content

With regard to the content which should be included in the curriculum consideration is given to the prior learning the students have obtained through their first cycle BSc. qualification (the subjects areas covered in the first cycle at UCD are summarised in Table 2) and that Engineers Ireland specifies six programme outcomes that apply to accredited professional engineering programmes. An outline of the modules followed is shown in Table 3. Examples of how the content of the programme satisfies each of these outcomes are discussed briefly below:

Programme Outcome (1): The ability to derive and apply solutions from knowledge of sciences, engineering sciences, technology and mathematics

The pre-requisites for the programme include BSc. subjects in basic science, engineering fluid mechanics, thermodynamics, mechanics, materials, continuum mechanics and surveying etc, in addition to a number of maths and maths physics courses. Also, the ME programme itself has a number of core and elective modules where the principles of engineering science and maths are employed e.g. Bridge Engineering.

Programme Outcome (2): The ability to identify, formulate, analyse and solve engineering problems;

In semester I of the programme a series of core Civil Engineering Design courses (CED 1 – 3) are taken. These build on the theoretical principles (structures, water and geotechnics) developed during the BSc. programme and apply these to real design problems. Whilst the learning in CED's 1 to 3 is classroom based, with the instructors using real-life case histories to develop design skills, a Project Based Learning (PBL) capstone course is run parallel with these modules. The PBL course has an open-ended question format, where each week an expert from industry gives a brief for a real engineering design problem and the students (in groups of four to six) have five days to compile a scheme (outline) design which has to be presented to the external expert and their classmates in a questions and answers type interruptible format.

Programme Outcome (3): The ability to design a system, component or process to meet specified needs, to design and conduct experiments, and to analyse and interpret data;

The design of components and systems is largely covered in a major design project module in Semester IV. Groups of two students will design either a major structure or a water system based on a typical brief from an industrial partner. This link with industry provides up to date design knowledge from industry and establishes a direct University-Industry partnership. There will be weekly one hour consultation periods with the industry mentor and students must develop their design independently in the interim periods using the knowledge accumulated through the programme.

Programme Outcome (4): The ability to design and conduct experiments, and to analyse and interpret data;

In semester III the students individually work on a major research project. They will initiate contact with one of the School's research groups, following discussion formulate a research proposal and a plan, undertake the research and write a major formal thesis.

Programme Outcome: (5) the ability to work effectively as an individual, in teams and in multidisciplinary settings together with the capacity to undertake lifelong learning;

The students undertake an individual significant research project, work in small groups (of two) in their design exercise, and work in groups of 4-6 in the PBL course. The effectiveness of group work is an area of concern and we have attempted to create efficiencies, encourage participation of all group members and thus provide improved outcomes by assigning defined roles within the PBL groups. These include a chairman (who's role is to direct group discussions), a timekeeper (charged with setting targets for key decisions and a scribe to record the decision making process). A significant effort to encourage/enable reflective learning throughout the programme will facilitate the development of life-long learning.

Programme Outcome (6): The ability to communicate effectively with the engineering community and with society at large.

The students are required to present scheme design solutions (usually in the form of sketches) for their PBL course. They will make preliminary and final report presentations (using PowerPoint) for their research project; will use sketches and preliminary calculations and finally drawings and calculation to communicate with their design mentor. There are significant requirements for the submission of written work in the form of the research thesis, laboratories and work experience reflection reporting. Core skills such as letter writing, CV preparation and communication with the general public are covered in the 2nd year course graphics and communications for engineers (See Table 3).

Programme Outcome (7): An understanding of professional and ethical responsibility

The theoretical background to meet this programme outcome is largely covered in the core module Engineer and Society. However, the importance of high professional standards and ethical responsibility are incorporated into all aspects of the course with an emphasis on good planning, consideration of the environmental implications of decisions made at the scheme design stage being emphasised in the design courses and strict written guidelines on the preparation and presentation of reports and particularly the rules with regard to acknowledging the work of others are given to all students.

4 Organisation and Sequence

The programme has a 2 year, single stage, and four semester framework, with 30 credits per semester. The students are graduates of UCD's BSc. programme (or

equivalent) and have completed three stages and accumulated 90 ECTS credits. The pre-requisites for entry to the programme are based on students completing a course of similar outline to the BSc. programme at UCD. (See Table 2). In particular courses which cover the theoretical framework in the major subject areas of Civil Engineering, namely; structures, hydraulics and soil mechanics are core requirements. The organisation and sequencing of the 120 credit ME programme is summarised in Table 3 and illustrated graphically in Figure 3.

Significant scaffolding (building on what is already known) is provided in the first semester. The Civil Eng. Design 1-3 modules build on fundamental engineering science; mathematics and mechanics principles developed in the BSc. course, and integrate these in real world design scenarios. Twenty-five of the credits in the first semester are core (including all the core lecture-based modules in the programme). This provides a backbone of coherence to the programme. The case-studies associated with the capstone PBL course associated with the design modules begins in week one of the first semester. By organising the students in groups of 4-6, the course not only aligns with many of the elements of Finks (2003) taxonomy of significant learning and the accreditation bodies specified learning outcomes, but it also encourages class interaction and staff/student interaction at the earliest stage of the programme.

In terms of progression, the modules are classified as *Basic*, which generally involve the application of basic principles learned in pre-requisite modules or are modules in non-discipline (Civil Engineering) topics. *Advanced* modules are ones which deal with specialist (usually intellectually challenging) topics which require the students to have completed the associated basic modules prior to enrolment. *Group*

modules are those in which the students work and are graded in a group. *Applied* modules are those specifically designed to apply the knowledge gained in basic or advanced modules. The term *core* refers to modules which are compulsory whilst *elective* modules allow the students significant scope to design their own course.

The sequence shown in Figure 3 is deliberately chosen to provide progression (i.e. basic modules are predominantly offered at the start of the programme and the more advanced modules build on this prior learning). This not only allows the student to solve increasingly complex problem, it affords multiple opportunities for reflection (revising basic concepts) in the context of a challenging problem. In addition module coordinators will be encouraged to pursue these concepts at a module level. For example, the first semester PBL course is based on the development of open-ended questions which are related to the course content from CED 1–3, and become significantly more complex throughout the semester and incorporate cross-disciplinary case studies (e.g. examining the interaction of the structural design for a large building with the geotechnical design of the foundations and basement structure). A major multi-disciplinary (double) case study is also organised in association with Architecture students, in which groups comprised of architects and engineers produce detailed proposals for landmark structures, such as bridges, considering public need, aesthetics, form, structure etc.

Since the first semester provides the core technical content necessary for accreditation the second semester offers considerable scope for specialisation through discipline specific electives which allow the coverage of advanced concepts. These are designed to allow the students to develop their theoretical and design skills in one

area of specific interest (Structures or Water). In addition there is considerable scope for students to take non discipline specific subjects such as Engineering business and law (most electives are run annually and therefore students have two chances to select their preferred modules).

In the third semester the students work on an individual major (20 credit) research project. In addition they take a five credit course in research methods and one free elective. In the final semester the students work in groups of two, to complete a major ten-credit self-directed design project (e.g. the complete design of a multi-storey building or bridge). Formal courses include two discipline specific advanced modules and two electives.

5 Evaluation Strategy

In the traditional product model, terminal exams i.e. backward-looking assessment (Fink 2003) is the standard method of evaluating student performance. In process based models it is important to consider a number of critical elements in the assessment procedure in order to enhance the quality of student learning:

- (1) The use of formative (forward-looking) assessment using real-life problems where possible
- (2) Introduce self-assessment to aid the students in evaluating their own performance
- (3) Spell out clearly the criteria and standards required and demonstrate clearly how excellence can be exhibited
- (4) Provide regular, timely, detailed and constructive feedback

Since it is of prime importance to encourage deep learning and complimentary skills by adopting an appropriate assessment method, the method of aligning programme learning outcomes to the assessment method and teaching and learning activities are presented in Table 4. Whilst multiple occurrences of matching outcomes to assessment and teaching and learning occur throughout the programme, the examples given in Table 4 demonstrate the variety of assessment methods adopted and illustrate the broader principle and can be used by module coordinators to aid alignment.

6 Conclusions

This paper describes the development of a Masters level course in Civil Engineering at University College Dublin. The impetus for the course design came from the need to expand the current 4 year bachelor's programme to a 5 year Masters programme in line with the requirements of the Bologna declaration. Whilst the content and programme outcomes of similar courses are widely discussed in the literature, particular attention was given here to the organisation, coherence and evaluation strategies of this programme as these are areas which must be designed into a course if order to promote the development of deep learning by the students. In doing so it is hoped that student engagement, staff and student satisfaction and educational attainment will be maximised. The additional time afforded by extension of the course from four to five years allowed the incorporation of a significant industry led design

project and the ability for students to pursue either advanced specialist Civil Engineering modules, complimentary modules in business and law or a combination of both.

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List of Abbreviations

ABET	Accreditation Board for Engineering and Technology
ASCE	American Society of Civil Engineers
BOK	Body of Knowledge
BSc.	Bachelor of Science
CED	Civil Engineering Design
ECTS	European Credit Transfer System
EUCEET	European Civil Engineering Education and Training
EHEA	European Higher Education Area
ME	Master of Engineering
PBL	Project Based Learning
UCD	University College Dublin

1. An ability to apply technical/scientific/mathematical principles
2. An ability to design components/systems
3. An ability to undertake critical thinking
4. An understanding of the need for and an ability to undertake life-long learning
5. An ability to operate in multi-disciplinary teams
6. An ability to communicate effectively
7. An understanding of professional and ethical responsibility

Table 1 Generic List of Graduate Competencies / Outcomes

Stage	Subject	ECTS Credits
Year 1	Chemistry for Engineers	5
	Graphics in Design and Communication	5
	Electronic and Electrical Engineering	5
	Mathematics for Engineers I	5
	Mathematics for Engineers II	5
	Mathematics for Engineers III	5
	Mechanics for Engineers	5
	Engineering Thermodynamics and Fluid Mechanics	5
	Physics for Engineers I	5
	Physics for Engineers II	5
Year 2	Environmental Engineering Fundamentals	5
	Building Construction	5
	Construction Materials	5
	Mechanics of Solids	5
	Graphics and Communications for Engineers	5
	Surveying	5
	Computer Applications in Civil Engineering	5
	Mathematics for Engineers IV	5
	Mechanics of Fluids I	5
	Mathematics for Engineers V	5
Year 3	Design of Structures	5
	Hydraulics	5
	Continuum Mechanics	5
	Professional Engineering	5
	Soil Mechanics	5
	Analysis of Structures	5
	Professional Engineering (Finance)	5
	Geology for Civil Engineers	5
	Mathematics for Engineers VI	5
	Numerical Methods for Engineers	5

Table 2 Core Civil Engineering modules for BSc. degree at UCD

Note: (1) Students take 10 core modules per year and two additional electives to accumulate 60 ECTS credits per year

(2) For details of modules <http://myucd.ucd.ie/program.do?program ID=62>

Semester	Module	Core/Elective	Credits	Classification
I	Civil Eng. Design 1	Core	5	Basic
	Civil Eng. Design 2	Core	5	Basic
	Civil Eng. Design 3	Core	5	Basic
	PBL	Core	10	Group/Appl
	Engineer and Society	Core	5	Basic
II	Choose four elective modules from discipline specific list	Elective	20 (5 each)	Advanced
	and/or Two basic electives in business law or advanced discipline specific electives	Elective	10 (5 each)	Basic/Advanced
III	Professional Work Placement	Elective	5	-
	Research Project	Core	20	Applied
	Research Skills	Core	5	Basic
IV	Design Project	Core	10	Advanced/Group
	Choose two elective modules from discipline specific list	Elective	10 (5 each)	Advanced
	and/or Two basic electives in business law or advanced discipline specific electives	Elective	10 (5 each)	Basic/Advanced

Table 3 ME Programme Summar

Programme Outcomes	Assessment Methods	Teaching and learning Activities
The ability to derive and apply solutions from a knowledge of sciences, engineering sciences, technology and mathematics	Summative exam	Lectures which make significant use of case studies to apply principle to design
The ability to identify, formulate, analyse and solve engineering problems	Continuous Assessment	Weekly case studies – Open ended question, groups present scheme design to peers/experts
The ability to design a system, component or process to meet specified needs	Final Design Report	Design Project – Students largely self-directed with one hour per week with design mentor
The ability to design and conduct experiments, and to analyse and interpret data	Major Thesis (70%) Prelim and final presentation (10%) Research proposal (10%), terminal interview (10%)	Research project – student proposes a research project, undertakes significant experimental work, interprets, reports and presents results in written, presentation and one to one format
The ability to work effectively as an individual, in teams and in multidisciplinary settings together with the capacity to undertake lifelong learning	Informal assessment during presentation (case studies) and interviews and weekly meetings (design and research project). Marks vary for different modules	A wide range of scenarios are presented throughout the programme from individual research project, two person design projects and 4-6 person PBL
The ability to communicate effectively with the engineering community and with society at large.	Informal continuous assessment during presentation (case studies) and summarise assessment of thesis/design report	Weekly presentations in case study, two presentations for research project, large thesis and design report
An understanding of professional and ethical responsibility	Contribution of all marks for continuous assessment and summative exam	Lectures and written guidelines

Table 4 Alignment of Programme Outcomes, assessment methods and Teaching/Learning

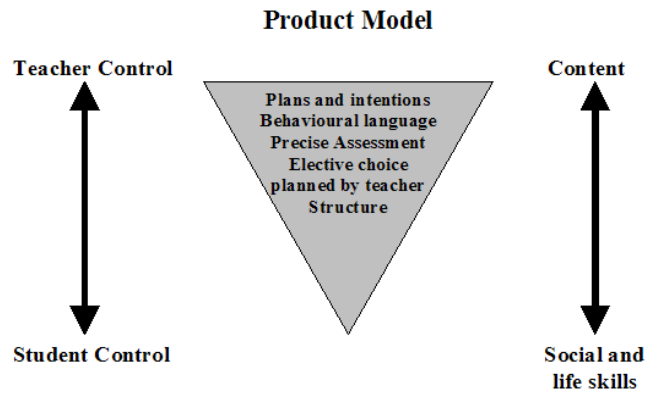


Figure 1 Product Model of Curriculum (after Neary 2003)

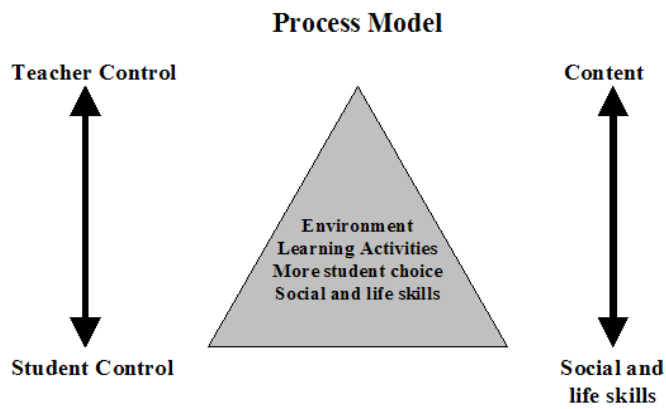


Figure 2 Process Model of Curriculum (after Neary 2003)

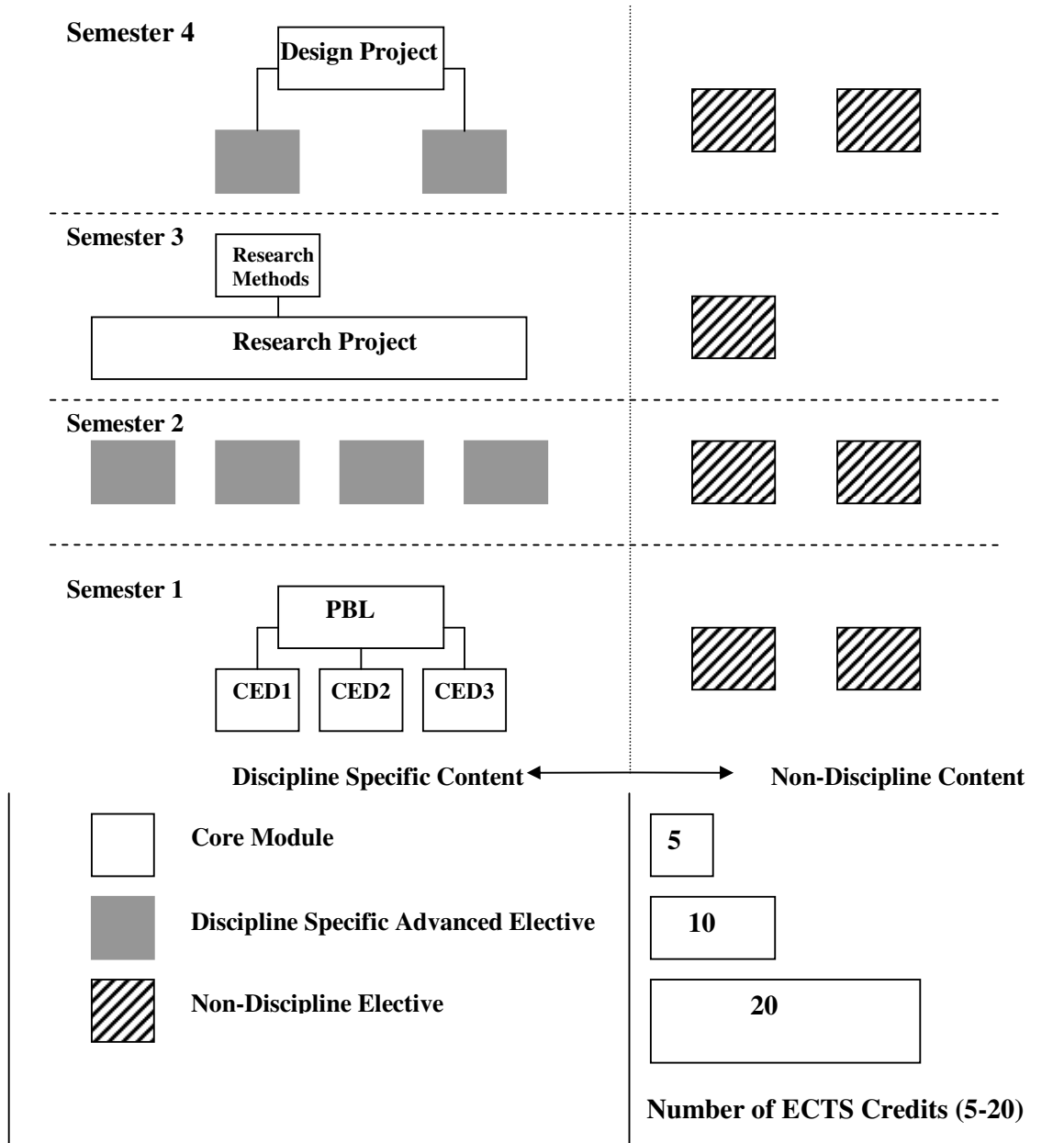


Figure 3 Graphical outline of ME structure