Top-down Synthesis of an Engineering Program of Study

Anthony Parker
Electronic Engineering, Macquarie University, Australia
tonyp@science.mq.edu.au

Daniel McGill
Electronic Engineering, Macquarie University, Australia
dmcgill@science.mq.edu.au

***Abstract**: A process is demonstrated for designing of a four-year program to deliver a balanced roll-out of engineering attributes within the constraints imposed by accreditation requirements and by the host institution. The starting point is the prescribed combination of the engineering attributes: background; specialisation; design and project; and professional practice. These are allocated across level of delivery. The design process is cast as an optimisation problem with a goal set for balanced development of the education from background in early years followed by deeper treatment of specialisation and professional components. Requirements for delivery and flexibility in student choice constrain the problem. The result is a specification of the required learning outcomes and a determination of numbers of teaching units that are common, that are allocated to a specialisation, or that can be offered flexibly.*

Introduction

A four-year engineering program is constrained by the accreditation requirements, rules of the host institution, and achievement of appropriate competencies. An accredited program is a prescribed combination of five engineering attributes: Background in science, engineering principles, and skills and tools; Specialisation appropriate to the discipline; Design and Project component; Professional Practice in engineering, management, and ethics; and an allowance for other elective studies, Bradley (2008). The program needs to develop appropriate competencies, which are distributed in several dimensions being the five engineering attributes; the specific disciplines—mathematics, physics, etc; the year of candidature; and level of delivery.

A top-down design of an engineering program can be cast as an optimisation problem. The goal is a balanced roll-out of the education components across year of candidature and level of delivery. The constraints are requirements for delivery by outside disciplines, flexibility in student choice and specialisation, and accommodation of a double-degree option.

The outcome identifies units of study that are common to the entire cohort and a definitive specification of the structure of the all teaching units in terms of educational components. This is not just the number or level of delivery but also the mix of education components that each should deliver.

Program Framework

Any program of study should be predicated on principles established by the accrediting body and the requirements of the university.

Engineers Australia has established a framework that is defined by engineering attributes and the proper development of learning outcomes, Bradley (2008). The framework should be structured to deliver engineering attributes in the prescribed proportion.

Table 1: Framework for an engineering degree. The bold-italic entries are discussed in the Implementation Section.

Study Unit Designation		*Engineering Attribute*						
		Background	**Specialisation**	**Design**	**Professional**	**Other**	**Total**	
Common	**Mathematics**	***3.0***					15	47%
	Computing	2.0						
	Physics	2.0						
	Engineering	***1.7***		***3.3***	***3.0***			
Final-year Design Project			0.7	3.0	0.3		4	13%
Specialisation Specific			6.0				6	19%
Engineering Options		***4.0***					4	13%
Elective						3.0	3	9%
Total		12.7	6.7	6.3	3.3	3.0	32	
		40%	21%	20%	10%	9%		100%

The student effort prescribed by Engineers Australia consists of, Bradley (2008):

- Mathematics, science, engineering principles, skills and tools appropriate to the discipline of study (not less than 40%)
- Engineering design and projects (approximately 20%)
- An engineering discipline specialisation (approximately 20%)
- Integrated exposure to professional engineering practice, including management and professional ethics (approximately 10%)
- More of any of the above elements, or other elective studies (approximately 10%)

University regulations prescribe a structure for delivery of teaching units, prerequisites, and flexibility of student choice, and graduate learning outcomes. In this case study, the structure consists of

- Minimum number of teaching units for a Bachelor of Engineering (32)
- Minimum number of teaching units in interdisciplinary education (3)
- Minimum number of teaching units to overlap with a double degree (7)
- Maximum number of first-year teaching units delivered by any one department (2)

Development of the Program Framework

The program framework can be viewed as a matrix of teaching effort allocated according to the engineering attributes versus the university regulations and requirements. Table 1 shows such a matrix with teaching effort quantified in terms of net number of teaching units, albeit that each may be distributed across more than one class or year. Across the engineering attributes, the teaching effort should accumulate to meet the minimum number of required teaching units. Across the university requirements, the teaching effort accumulates to meet the required proportion of engineering attributes.

In this case study, the university's three-teaching-unit interdisciplinary education requirement neatly amounts to the 10% elective-studies attribute requirement. These three units are the Other/Elective entry in Table 1.

The requirement for seven teaching units of overlap to accommodate a double degree should be considered as a background attribute because the inherent flexibility creates uncertainty as to which units any student may enroll in. The seven units include the three electives, which would be common

Table 2: Staging of development engineering attributes. The bold-italic entries are discussed in the Implementation Section.

Teaching Units	Introductory	Intermediate	Advanced	Professional	Total	
Background	7.0	***3.6***	2.0		12.7	40%
Specialisation		2.0	3.0	1.7	6.7	21%
Project	0.7	***0.7***	1.0	4.0	6.3	20%
Professional	0.3	***0.7***	1.0	1.3	3.3	10%
Other	3.0				3.0	9%
	11	7	7	7	32	100%

to both degrees. The remaining four units become the Background/Engineering Options entry in Table 1.

To manage the engineering discipline specialisation attribute as a separate stream of teaching units, a Specialisation Specific set of units is defined. There are six teaching units that make up the approximately 20% requirement entered in Table 1.

A substantive final-year design project is a common feature of most engineering degree programs. In this case a half-year teaching effort (equivalent to four teaching units) is allocated to this project. Although students may enrol in a common project unit, it is reasonable to expect that the subject of the project would be aligned to their specialisation stream. This four-teaching-unit class is entered in Table 1 as a Final-year Design Project with attributes distributed across Specialisation, Design and Project, and Professional Practice.

The remaining teaching units in the program are common for all students regardless of specialisation. They therefore fulfil the background requirement and do not contribute to the Specialisation or Other attributes. Because professional practice is regarded as a common requirement, three teaching units are allocated to it in Table 1 together with a contribution from the project to fulfil the 10% Professional requirement. Design and project attributes should be developed before a student is expected to confront a final-year project, so an effort equivalent to 3.3 teaching units are included in Table 1 to contribute along with the project to the fulfilment of the 20% Design and Project requirement.

A pragmatic principle that underpins and informs the development of an engineering program is that the curriculum can incorporated teaching units from outside an engineering department. It would be reasonable to expect contributions from the Departments of Physics, Mathematics and Computer Science who would deliver service units, which are entered in Table 1 as Background only.

There remain eight Common teaching units that are clearly under the auspices of the Engineering Department. This allows control of the distribution of the attributes of background, design, and professional practice across these eight units.

Staging of Attribute Development

The staging of engineering education ranges from introductory, intermediate, advanced, through to professional levels of treatment. Typically, each level corresponds to a respective year of candidature. Each of the five engineering attributes should be developed through these levels in a balanced manner.

Table 2 identifies the staging of the development of engineering attributes across academic level in terms of numbers of teaching units. For each attribute there is a sequence of teaching units over a range of levels.

- Background attributes are focused at the introductory level and become less intensive at higher levels.

- Specialisation attributes are developed in the intermediate and advanced levels with a finishing component at the professional level.
- Design and project attributes are developed through all levels and lead to a major professional-level project.
- Professional attributes are steadily developed across all levels with deeper concepts introduced as the students mature.
- The Other component is necessarily an introductory-level exposure to interdisciplinary fields of study.

The entries in Table 2 were derived through an optimisation process constrained by several factors. The tally of units in each attribute should be consistent between Tables 1 and 2. There is a requirement that any set of teaching effort in these tables can be delivered within sets of individual units.

The goals are to achieve a balance of teachings units across all levels and to deliver a common program to all students in the first three semesters. The consequence of the latter is to enable the students to gain the requisite background skills prior to choosing their area of specialisation from semester four.

The framework in Tables 1 and 2 define sets of teaching units at specific levels. Since those required to develop engineering aspects are those under the auspices of the Engineering Department, an integrated sequence of units across several semesters can now be designed within this framework.

There is also a position within the framework for a sequence of specialisation units. This allows the easy incorporation of new specialisations.

To complete the design of the program, it is necessary to map the learning outcomes across the framework.

Professional Engineering Competencies

Many Australian universities have developed a series of Graduate Attributes that are used to define the pedagogical features of their graduates. Generally, these are commensurate with the graduate outcomes as defined by the Competency Standard proposed by Engineers Australia, Bradley, (2006). The shared values represented by these two requirements enable the Engineering program to be compliant with both these sets of learning outcomes.

For the development of the program it is therefore sufficient just to consider the Professional Engineering Competencies (PEs).

Allocation of Learning Outcomes

An example of an allocation of some of the PEs is given in Table 3. In this table the PEs are those based on Anderson (2001) proposed in Trevelyan (2009).

Each Professional Engineering Competency is allocated to one or more engineering attributes and developed across one or more academic levels.

The treatment of each competency at each point is considered to be one of the following four designations:

1. Prerequisite Competency (designated P in Table 3).
   This is an assumed competency that forms an aspect of the general entry requirements as defined by the University, so is not overtly taught within the Engineering curriculum.
2. Taught Competency (designated T in Table 3).
   This is a skill that necessarily features throughout the curriculum and is taught and assessed at this point. The recurrence of teaching of a competency across academic level indicates the introduction of new concepts at a deeper or more mature level.
3. Utilized Competency (designated U in Table 3).
   This is a skill that is utilized at this point, which implies knowledge of the competency and that assessment will be contingent on it. It is assumed that the student would have been either taught the skill at a previous point or it was a designated prerequisite.
   It is a given that the utilized competency may need to be augmented by further teaching, so this

Table 3: Illustration of the distribution of Professional Engineering Competencies across four levels (years). This is a subset of the complete matrix that demonstrates the principle.

	Introductory				Intermediate					Advanced				Professional			
	Sci Background	Eng Background	Design / Project	Professional	Sci Background	Eng Background	Specialisation	Design / Project	Professional	Eng Background	Specialisation	Design / Project	Professional	Specialisation	Design / Project	Professional	Industry Exp
PE1 ENGINEERING EXPERTISE																	
PE1.1 Foundation knowledge in mathematics, science and engineering fundamentals																	
Mathematics	T	T			T	***T/U***	T/U			T/U	T/U			D	D	D	
Application		T			U	***T***	T	***T/U***			T/U	T/U		D	D		
PE1.2 Discipline expertise																	
Fundamentals						***T***		***T***		U		T		D	D		
Evaluation		T				***T***	T	***T***		U	U	U		D	D		
PE1.3 Software tools																	
Use of	P/T	P/T	P/T	P/T	T	***T***	T/U	***T/U***	***T/U***		T/U	T/U	T/U	T/D	D	D	
PE1.4 Test and measurement																	
Measurements	T/U	T/U	T/U		T/U	***T/U***	T/U	***T/U***			U	U		D	D		
Errors						***T***	U	***T***			U	U		D	D		
PE2 ENGINEERING EXPERTISE																	
PE2.2 Sustainability																	
Social context				T					***T***				T		T/D	T/D	
Standards									***T***			T	T		T/D	T/D	
PE2.4 Design																	
Constraints								***T***				T			T/D		
Alternatives			T					***T/U***				T/U			T/D		
PE2.5 Projects																	
Conduct			T					***T/U***				T/U			T/D		D
Planning												T/U			T/D		D
PE2.6 Business context																	
Management															D	T/U	T
Commerce													T		D	T/U	T
PE3 PROFESSIONAL ATTRIBUTES AND SKILLS																	
PE3.1 Communication																	
Conversation	P/T	P/T	T	T	T	***T***	U	***T***	***T***		U	T	T	U	D	U	U
PE3.2 Information																	
Research			T					***T***				U		D	D	D	
PE3.4 Understanding of professional and ethical responsibilities, and commitment to them																	
Ethics				T					***T***				T		U	T	U
Legislation													T		U	T	T/U
PE3.5 Coordination and team work																	
Coordination		T				***T***		***T***	***T***			U	U		D	U/D	U
Interaction								***T***				U	T		D		U
PE3.6 Self Management and professional development																	
Personal limit		T	T	T		***T***	T/U	***T/U***	***T/U***		T/U	T/U	T/U	T/U	D	D	
Planning	T/U	T/U	T/U	T/U	T/U	***T/U***	T/U	***T/U***	***T/U***	T/U	T/U	T/U	T/U	T/U	D	D	

element is often present in conjunction with the Taught designation. One feature of this particular level of treatment is that in the transition from Taught to Utilized the skill may be expected to be implemented as soon as it is initially presented to the student.

4. Demonstrated Competency (designated D in Table 3).
   This is a skill that is expected to be demonstrated by the student with minimal supervision. This level of competency treatment indicates an assumed of knowledge and mastery. Significantly, these competencies recur in the final units of a specialisation and particularly in final project work.

Implementation

The next step in the design of the program is the distillation of the competency matrix (Table 3) into individual teaching units. To demonstrate this, consider the design of the intermediate, common teaching units to be delivered by the Engineering Department. The relevant entries in the tables have been highlighted in bold-italic type.

Five teaching units are allocated to non-specialist, intermediate attributes in Table 2. These need to be drawn from corresponding entries in Table 1. In this example it was decided, with the benefit of experience, that two teachings units would be drawn from the four Engineering Options units and one unit from the three Common Mathematics units. This leaves two of the eight Common Engineering Department units that should be delivered at this intermediate level.

From Table 2, the two common, intermediate, engineering teaching units need to deliver Background, Design and Project, and Professional Practice attributes in proportions of 0.6, 0.7, and 0.7 respectively. Table 3 gives the Professional Engineering Competencies that should be implemented in these two units. These include Engineering Background, Design and Project, and Professional Practice attributes that should be taught or utilized (as highlighted in Table 3).

The competencies should be addressed by the two units as a pair rather than in any one of them. This requires collaboration between the academics in charge of each during the detail design of their curriculum. Moreover, the intermediate teaching units form part of an Engineering Background stream across all academic levels, so curriculum design needs to be managed at a higher level.

Conclusion

The top-down process presented here has lead to a matrix (Table 3) of learning outcomes and competencies in terms of academic level and engineering attributes for a complete engineering program. Table 3 gives the developmental path for teaching, utilising, and demonstrating each competency across the whole degree.

In this process, the design of the curriculum for individual teaching units can be guided by the requirements of Table 3. This becomes a straight-forward process because the matrix identifies the sequence of competency development relative to the position of the individual teaching unit within the whole degree.

The new and unique consequence of the process presented here is that the teaching units are no longer a sequence of technical content in individual semester packages or of single engineering attributes in isolated teaching units. Rather all aspects of the curriculum are integrated so the student development is consistently and thoroughly developed.

References

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