

A systematic consultation process to define graduate outcomes for engineering disciplines

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Abstract: *In many countries around the world, there is considerable interest in the development of robust learning outcomes for engineering and other higher education programs. These outcomes underpin the accreditation systems operated by ABET, Engineers Australia, IPENZ, EUR-ACE and the Washington Accord members. In addition, many national governments are developing quality assurance processes that will require university programs to deliver an agreed set of learning outcomes. This paper addresses the development of a systematic, data-driven methodology to develop such learning outcomes.*

Introduction

The aim of the Define Your Discipline (DYD) project, funded by the Australian Learning and Teaching Council (ALTC), is to identify and develop an efficient, effective and inclusive consultation process that can be used by discipline stakeholders to define graduate outcomes for programs in their discipline such as engineering, law or pathology. The consultative process has been trialled nationally to develop graduate outcomes for the environmental engineering discipline in the first instance.

This paper describes the DYD stakeholder consultation process that was used in 2010 to capture the views of environmental engineering stakeholders, including academics, practitioners, and recent graduates. The project team worked closely with an Environmental Engineering Project Reference Group which was formed by Engineers Australia's Environmental Engineering College. The College organised the stakeholder consultation workshops, which were held in all mainland capitals. This ensured that data was collected from environmental engineers from both industry and academia.

Context

There is a substantial body of literature that defines the kind of competencies that young graduates should have as they emerge from universities ready for the engineering workplace. These include the US ABET requirements and those from Engineers Australia. In addition, most Australian universities have published a set of generic graduate attributes that would be acquired by all undergraduate students, including engineering students, by the time they graduated from their program. Recent work in Australia also includes the development of Threshold Learning Outcomes for the combined discipline of

Engineering and ICT (ALTC, 2010). A comparison of these competency statements with other international reference statements is included in that publication.

Although these statements are used in national accreditation processes, there is a concern that they are very generic and they fail to capture the technical specifics of each discipline, such as civil engineering or environmental engineering. For example, Engineers Australia's 2011 Stage 1 Competency Standard for the Professional Engineer (Engineers Australia, 2011) lists the expected graduate competencies for undergraduate engineering programs in three clusters of competency under the headings: 1. Knowledge and Skill Base; 2. Engineering Application Ability; and 3. Professional and Personal Attributes. To satisfy Element of Competency 1.3, a graduate must demonstrate 'In-depth understanding of specialist bodies of knowledge within the engineering discipline'. The question is: what specific technical knowledge, skills or understandings are essential for a graduate to commence practice in each of the disciplines overseen by the Engineers Australia Colleges?

Some disciplines have made an effort to define the nature of the discipline through more detailed statements. Recent examples include the ASCE Body of Knowledge project (ASCE, 2008) and the American Academy for Environmental Engineers in the US (Arlotta, Baillood et al, 2008). The Australian Environmental Engineering College also defined the nature of their discipline prior to 2004 and this resulted in the publication of the 'Guidelines on the Design of Environmental Engineering Undergraduate Courses' which is still in use.

While undergraduate engineering education in Australia enjoys a world-class accreditation system, the processes used by individual Engineering Faculties and Schools to re-orient and update curriculum are often ad-hoc (Carew & Cooper, 2008; Walkington, 2002). Those leading curriculum renewal in an engineering discipline generally rely on input from a local industry advisory group, internet searching to establish what the top international Schools and local competitors are teaching (or professing to teach), and gut instinct on national standards and the likely future direction of the discipline as a whole.

King recognised the need for improved curriculum development processes in engineering by calling for 'systematic and holistic educational design practices with learning experiences and assessment strategies that focus on delivery of designated graduate outcomes' in engineering (King, 2008, p. 13). The establishment of clear and agreed national standards in the form of Discipline-specific Graduate Outcomes (DGO) would provide a sure footing for engineering discipline leaders who are reorienting their undergraduate programs to meet current and emerging trends in the discipline.

The DYD Project focuses specifically on Element of Competency 1.3 and through consultations with key discipline stakeholders seek to answer the question 'What exactly does a graduate from this discipline need to know, understand or be able to do to claim in-depth technical competence in this discipline?' While Element of Competency 1.3 is the focus of the study, many other competencies have been discussed and contextualised so they better reflect the essential (and desired) Graduate Outcomes of the subject discipline.

The Project Team believes it is more efficient to undertake this work at a national level so that all Engineering Schools can use the same industry authenticated DGOs as a starting

point for curriculum renewal. A national approach also overcomes the risk that a School could face if its local stakeholder-defined graduate outcomes were not aligned with the views of the current executive members of the relevant Engineers Australia College, or their representative on an Accreditation Panel. The Project Team addressed these issues by developing the DYD consultative process to invite, value, and integrate the views of the sometimes disparate groups of stakeholders, while keeping a 'futureproofing' mindset that focuses on the skills graduates will need in 10 to 20 years rather than current requirements. It is expected that the resulting set of Discipline Graduate Outcomes will be adopted by the relevant College and published and maintained by Engineers Australia. They will then be used by Engineering Schools to inform curriculum development and as a guide by members of future Accreditation Panels. This will ensure that they are reviewed on a regular basis, applied in curriculum renewal, and sustained into the future.

Research Questions

The aims of the DYD project are:

1. To identify and develop an efficient, effective, and inclusive consultation process that can be used by discipline stakeholders to define practitioner-authenticated Discipline Graduate Outcomes.
2. To use the consultative process to deliver nationally agreed Discipline Graduate Outcomes for an engineering discipline.

While conducting the Project, the team is seeking to validate the authenticity of these outcomes by conducting research to test the following hypotheses:

- The DYD Stakeholder Consultation process is an effective, efficient and inclusive process;
- The DYD Stakeholder process enables new and future perspectives to be synthesised with traditional constructs in the development of authentic graduate outcomes.

Theoretical Framework

Numerous tools have been used to develop and authenticate graduate outcomes, particularly for the development of competency-based curriculum in the vocational education sector. For example, occupational analysis tools can be used to observe workers, a curriculum can be developed using the DACUM process (CETE, 2011), and the Delphi technique can be used to iteratively gather and synthesise data from stakeholders until consensus is reached.

The DYD Stakeholder Consultation process is based on the Modified Delphi Technique (Custer, Scarcella, & Stewart, 1999), and uses aspects of the DACUM job analysis method. The design of the process was based on an issue, the definition of a set of graduate outcomes, rather than a method (Gregory, Fischhoff, Thorne, & Butte, 2003), and was informed by the results of a stakeholder analysis (Reed et al., 2009). The analysis determined who had a legitimate stake based on their knowledge and interest.

The self-appointment method was adopted to recruit workshop participants and a selection method was used to form the group of experts who are overseeing the process (Catt & Murphy, 2010). The DYD process was designed to ensure that the input from each stakeholder is equally valued so that the opinions or biases of individuals or groups do not impact on the final outcome. For example, the individual nature of data gathering process ensures that dominant personalities, the professional standing of individuals, or group thinking do not influence the data. The metadata gathered with the data will enable the Project team to assess the influence of each data set, each participant and each stakeholder group on the defined set of graduate outcomes.

Method, Data, Analysis

The DYD Stakeholder Consultation workshop begins with a divergent phase. Each workshop participant is asked to write down the tasks that they believe a graduate should be able to do in their first year for two after graduation, including supervised tasks. After an initial period (usually about 30 minutes) the participants at each table collaborate to generate additional tasks. Participants then begin the second stage of the process, the convergent phase, by performing a cluster analysis. This involves laying out all the tasks on a large flat surface and looking for commonalities. The tasks are then grouped and gaps are identified. New task statements are written to cover any gaps. The workshop concludes when the groupings are agreed, and the order of each task in a group is finalised.

The DYD stakeholder consultation process ensures that the contributions from individual participants, as well as stakeholder groups, is captured as the data supplied by each person is identified and each task is numbered. This allows the Project team to track each task through the grouping and synthesis process. The data was analysed for consistency and differences before being synthesised and elaborated using a group of experts to form a set of draft graduate outcomes.

Findings

Table 1 shows raw data from several categories from one of the workshops. This shows the kinds of tasks that workshop participants identified for recently graduated environmental engineers. The Table shows the results after the clustering process.

Table 2 shows the clusters from five of the eleven workshops held in 2010. Note the consistent appearance of several of these, such as Design, Modelling, Auditing, and Management.

What has been interesting about the results of this process is that the cluster analysis yielded quite unexpected results. Our hypothesis was that clusters would form around application areas in environmental engineering: soil problems, water, energy, noise, air pollution and so on. Thus, we expected that these statements would, together, form a more detailed layer in the graduate outcomes hierarchy, one step below, and expanding on, Engineers Australia's Stage 1 Competency Standards.

Table 1 - Tasks performed by recent environmental engineering graduates

Process	Examples of identified tasks
Investigation	<ol style="list-style-type: none"> Executes simple sampling plans for collection of air, water and soil samples. Collect, evaluate and interpret water quality data and prepare a report on the results and recommended solutions to improve the water quality.
Audit and compliance	<ol style="list-style-type: none"> Audit the environmental compliance of a small, low complexity project against its environmental approval or management plan. Undertake audits of specific sites or parts of an organisation to identify adequacy of current practice against significant environmental aspects of the operation.
Design	<ol style="list-style-type: none"> Contribute to contaminated site remediation design/strategy. Design a catchment management plan for both groundwater and surface water catchments.
Modelling	<ol style="list-style-type: none"> Develop inventories of emissions including the physical, chemical and spatial characteristics of the sources. Manipulate and combine data to arrive at assessment of aggregate effects. Calculate mass balances and identify flux paths e.g. water or nutrient.

Table 2 - Clusters from each of the workshops

Event	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Other clusters
1	Investigation	Environmental impact assessment	Design	Modelling	Auditing	Environmental management and plan	Risk assessment
2		Environmental impact assessment	Design	Modelling	Auditing	Environmental management and plans	Data collection & analysis Communication Project management
3			Design	Modelling	Auditing	Environmental management and reporting	Data collection Implementation Evaluation
4	Site history Site investigation	Environmental impacts	Design solutions	Conceptual model	Auditing	Site management options	Communication Data mining /analysis Project management
5		Impact assessment	Design		Situational reporting & monitoring	Management plans and Programs (Risk)	Stakeholder engagement and communication

Instead, clusters consistently formed around six major work types: *investigation, impact assessment, design, modelling, audit and compliance, and environmental management*. Of these, half of them are quite generic skills – investigation, design and modelling. The remaining three have a distinctly environmental feel – impact assessment, audit and compliance, and environmental management.

So, how do these compare to the common accreditation requirements as discussed earlier? Table 3 shows such a comparison.

What is interesting about this is that the categories created at the workshops are almost solely from category 2 of the EA accreditation guidelines, namely “Engineering Application Ability”. Categories 1 (Knowledge and Skill Base) and 3 (Professional and Personal Attributes) are listed in Table 3 for completeness.

Considered also with the application domains in environmental engineering (land/soil, water, air, noise, energy, etc), the whole picture becomes rather complex, with at least three axes of knowledge and skills required:

- Application types – investigation, design, modelling, impact assessment, management, audit and compliance
- Application areas – soil, air, water, noise, energy, etc
- Professional and personal skills – communication, teamwork, ethics, information, self management and evaluation, etc

Each of these is underpinned by a sound body of knowledge and skills (EA’s category PE1).

We propose a *three dimensional model* (Table 3 and Figure 1) to represent the scope of the environmental engineering discipline. Other disciplines share some aspects of this model.

Table 3 – Comparison of 6 work types with Engineers Australia’s accreditation guidelines

Dimension	Category	Engineers Australia Element of Competency
1	Investigation	2.1. Application of established engineering methods to complex engineering problem solving.
	Modelling	2.2. Fluent application of engineering techniques, tools and resources.
	Design	2.3. Application of systematic engineering synthesis and design processes.
	Impact assessment	1.3. In-depth understanding of specialist bodies of knowledge within the engineering discipline. (Indicator: Proficiently applies advanced technical knowledge and skills in at least one specialist practice domain of the engineering discipline).
	Environmental management	2.4. Application of systematic approaches to the conduct and management of engineering projects.
	Audit and Compliance	1.6. Understanding of the scope, principles, norms, accountabilities and bounds of contemporary engineering practice in the specific discipline.
2	Generic skills	1.2. Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline. 3. PROFESSIONAL AND PERSONAL ATTRIBUTES 3.1. Ethical conduct and professional accountability 3.2. Effective oral and written communication in professional and lay domains. 3.3. Creative, innovative and pro-active demeanour. 3.4. Professional use and management of information. 3.5. Orderly management of self and professional conduct. 3.6. Effective team membership and team leadership.
3	Engineering applications	1.1. Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline. 1.3. In-depth understanding of specialist bodies of knowledge within the engineering discipline. 1.4. Discernment of knowledge development and research directions within the engineering discipline. 1.5. Knowledge of contextual factors impacting the engineering discipline.

Where to from here?

The work in 2011 is confirming the results through additional workshops, elaborating the work types in more detail in specific application areas, such as contaminated land.

The intention is also to develop a range of task-oriented learning materials and project ideas that will help academics to teach the six core skills. These learning resources will be made available via the web. Contact the authors if this is of interest to you.

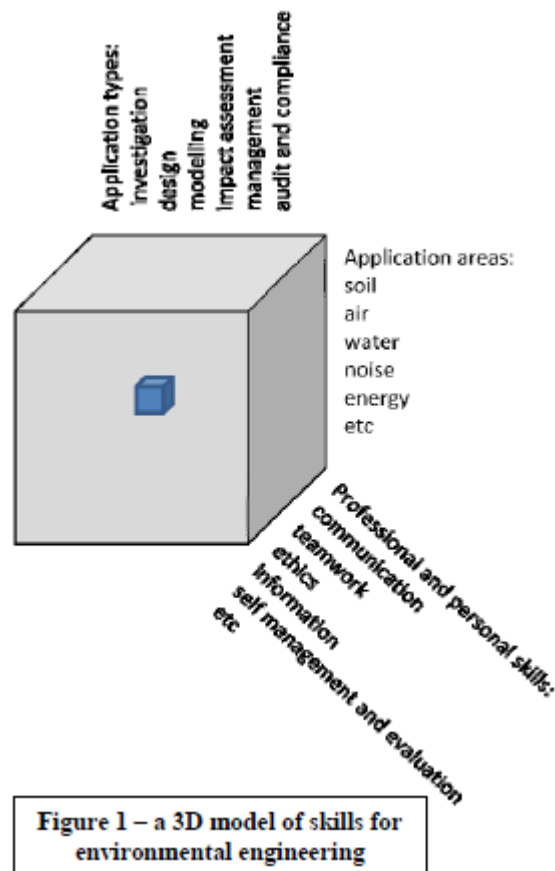
Conclusions

The workshops from this process have demonstrated surprisingly consistent outcomes for the scope of environmental engineering, with six aspects of environmental engineering work identified. The same process is being tested in other disciplines. The results confirm the accreditation framework used by Engineers Australia (which is well aligned with other accreditation bodies around the world through the International Engineering Alliance).

The authors have also proposed a three dimensional model for understanding the complexity of these learning outcomes, embracing application types (kinds of work), application areas (domains of application), and general purpose professional and personal skills that underpin engineering work. This should be similarly useful in other domains of engineering.

We believe that current accreditation processes tend to oversimplify the complexity of engineering practice, which is better represented by the three dimensional model shown. Engineering curricula must help students to learn skills and knowledge on each of these three dimensions within a limited period of 4-5 years and a limited number of subjects.

The challenge for good curriculum design is to provide adequate coverage of all of the key skills, which requires that many subjects will have three separate purposes: developing skills in one of the six application types, familiarising students with one of the application areas, while also continuing to develop their professional and personal skills. That makes curriculum design challenging and it makes teaching challenging, but also more rewarding, because each subject needs to blend together these three learning factors, combining theory with practice, underpinned by professional skills.



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