

Teaching and Learning in Engineering Education: Constructive

Alignment

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Abstract

Successful learning in engineering is more than the accumulation of technical facts and laboratory skills. Consequently, teaching in engineering, while not unique, is unlike many other disciplines. It is not simply a transferral of knowledge to students. In addition to the development of factual knowledge, it involves developing students' skills in applying that knowledge to novel situations and problems. Students seek to succeed in their learning at the level of single courses and also seek to make a transformation from non-engineer to engineer.

The better understanding of how students in engineering education learn successfully requires an analysis of the quality of teaching. Biggs [1] discusses the concept of reflective practice in the terms of individual practitioner and the institution. However, the institutional model seems to assume that the same quality model that suits, for example, physiotherapy or recreation management, will suit engineering. Therefore the quality model needs to be discipline-specific with a common institutional core of things like graduate qualities and constructive alignment. We propose to fill this gap to make the quality model reflective of the discipline-specific needs.

This paper describes a model that is placed in between the individual and the institution. We propose that this gap is at the level of the discipline, and must be filled by a quality framework that bridges the divide between individual, reflective teachers and the reflective institution. In other words, we propose the concept of the reflective *discipline* and examine this for the case of engineering education.

Keywords: constructive alignment, reflective practice, quality in education.

The Concept of Reflective Discipline

Ensuring the best quality of teaching and learning in universities has been always a matter of concern. Biggs [1] addresses the issue of quality in higher education by proposing an extension of Schon's [2] concept of the reflective practitioner to the notion of a reflective institution. Biggs encapsulates the reflective practitioner concept in three questions: "an individual teacher, for example, might ask: what is my espoused theory of teaching"? The reflective practitioner also examines how his or her practice matches the theory and "how can my theory help me teach more

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effectively”? Lastly, the reflective practitioner also seeks to understand what impediments limit the matching of practice to theory [1].

By the same token, the reflective institution must address three issues on the path to quality teaching and learning. Biggs [1] summarises these as:

1. A Quality Model (QM) that identifies the institutional theory of teaching that underpins teaching and learning in the organisation.
2. A Quality Enhancement (QE) improvement process that facilitates improvements to teaching and learning in response to changes to the environment.
3. A Quality Feasibility (QF) process that investigates and removes impediments to good teaching practice in the institution.

While we agree with the model of a reflective institution to augment the concept of the reflective practitioner, we argue that there is a gap that must be filled if reflective practice and, ultimately, successful teaching and learning is to be achieved. We propose that this gap is at the level of the discipline, and must be filled by a quality framework that bridges the divide between individual teachers, who may or may not be reflective practitioners, and the reflective institution. In other words, we propose the concept of the reflective discipline and examine this for the case of engineering education.

The concept of reflective practitioners, a reflective discipline and reflective institutions leads to a complex model of quality in higher education. Ideally a reflective institution will espouse a quality model that allows enough flexibility for disciplines to adopt the theory, or theories of teaching that are best suited to that discipline. The quality model of an institution must not assume a “one size fits all” approach.

This model highlights important relationships between the three reflective elements: (1) individual, (2) discipline and (3) institution in different quality concepts (Table 1).

Table 1. Reflective elements in different quality concepts.

Quality Concept	Individual	Discipline	Institution
Model	What is my theory of teaching?	What theory or theories of teaching are best for this discipline?	What theory or theories of teaching fit this University’s aims?
Enhancement	Practice and theory? Effectiveness?	Disciplinary process improvement?	Institutional improvement process?
Feasibility	Individual impediments to improved teaching?	Disciplinary impediments to improved teaching?	Institutional impediments to improved teaching?

For example, for the quality feasibility concept, an individual teacher might ask a question “what impediments prevent me from improving my teaching quality”? One of the possible answers might be: lack of training in education. For the disciplinary element a possible impediment might be: lack of industry experience among academics. And for institutions, promotion criteria based mostly on research output might be an impediment for improving teaching.

The relationship between the three reflective elements is important.

The *quality feasibility* needs to be discipline-specific and a modified version of the institutional model. That's because the way of removing impediments to good teaching may vary widely from one area to another. A school of education, for example, probably has different problems than an engineering school.

To be fully effective we believe that a reflective institution will formulate a flexible *quality model* that can accommodate discipline-specific theories. At the same time, the quality model will steer the individual practitioners towards a theory of teaching that is consistent with the discipline.

For the *quality enhancement* concept it is also important to look at the model as a whole considering the relationships between the reflective elements. For example, for individual teachers to achieve their individual performance management goals for improving teaching effectiveness they need to understand the “big picture”. The assigned goals need to align with the strategic directions in quality of teaching and learning for the whole institution taking into account the specific elements of the disciplinary environment.

Successful Learning in the Concept of Reflective Discipline

In [3] the assertion was made that successful learning is characterised by, and is an holistic combination of: (a) achievement of expected outcomes in individual courses, (b) achievement of expected outcomes for the whole Degree, and, (c) achievement of 'Graduate Qualities'.

The following sub-sections address these three components, and explain the role of each in defining successful learning in the concept of reflective discipline.

Individual Subjects.

At the University of South Australia (UniSA), individual courses outcomes are captured in the Course Information for each course in a degree. This document expresses the key information for a course, including contact hours, aims, objectives, syllabus, assessment procedures and reference material.

The “aims” generally focus on the individual course, but may link the material to later course. The statement of “objectives” for the course is an expression of the desired result, or outcomes, of the learning process for the subject. There is a mapping of objectives to corresponding aims. Successful learning therefore consists, in part, of meeting these objectives (thus fulfilling the intent of the course). It is further distinguished by the degree of achievement of each objective.

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It is tempting to define successful learning as ‘the degree to which the assessment criteria in the subject have been met’. Practical experience of teaching in higher education suggests that there may be a wide degree of variation between the stated, desired outcomes of a course and the assessment procedures which are described in the very same course statement. This problem is addressed in [4], for example.

Whole -degree Outcomes.

Successful learning for the system or ‘whole Degree’ level is not simply the sum of the successful learning in individual subjects. This statement expresses a characteristic of complex systems - that the whole is greater than the sum of the parts [3].

Graduate Qualities.

Graduate qualities [5] define a set of characteristics of UniSA graduates which are believed to be valuable and necessary to extracting the maximum benefit from University education. They are applicable to all Degrees in the University. The view of successful learning in this paper deliberately sets these apart from the transformation criterion in the previous section because, while it is desirable that all engineers achieve the graduate qualities, achievement of the graduate qualities alone does not make a graduate an engineer.

In summary, successful learning in the discipline of engineering is (or should be) a combination of:

- achieving the desired outcomes (objectives) of individual courses
- combining these, and achieving the desired emergent system outcomes (a transformation from layperson to engineer) of the whole Degree, and,
- achieving specific, generic graduate qualities that may be only indirectly related to the discipline.

Understanding of How Students Learn Successfully.

In the context of this discipline (engineering) it is proposed that four factors are necessary in determining how students might learn well. A short outline of each is given.

What Constitutes Successful Learning in the Discipline?

It is necessary to have a clear conception of the objectives of a particular program of study (what is to be learned?) in order to be able to judge whether students are succeeding. Emphasis here is that learning should be more than simply meeting the objectives. Rather, the degree of success is also important. Student perceptions of the assessment system have a powerful impact on their approach to learning tasks [6]. It is apparent that many forms of assessment used in engineering unwittingly encourage poor learning practices and as a result confuse the definition of successful learning. This issue is covered in [4].

Student Conceptions of Learning.

Students learn well if their concept of learning is in harmony with what is appropriate for the material.

Previously this paper identified an important element of successful learning as the successful transformation of the student, from layperson to 'engineer', over the course of a Degree program. This conception of learning, that of 'changing as a person' [7] extends Säljö's [8] hierarchy of conceptions and represents a desirable progression from conceptions which are characterised by an external locus of control (where students are effectively dependant on others for their learning) to conceptions characterised by an internal locus of control (where the student becomes increasingly self-motivated, self-directed and responsible for his/her learning).

The question is then one of seeking to facilitate this transition from simple conceptions of learning (and the characteristics they embody) to sophisticated conceptions with corresponding desirable characteristics. This may be most readily achievable through careful construction of assessment methods to match, and influence, desired outcomes and conceptions of learning, both at subject level, and, particularly, at whole-Degree level. For example, less emphasis on exams (and memorisation) may be appropriate, and should be replaced with assessment that emphasises the application of knowledge, development of understanding and interpretation of knowledge.

The transformative conception, however, is perhaps more readily developed, not by assessment procedures, but through engaging in activities that reflect the desired transformation. For example students in engineering should be given opportunities to work in teams, interact with real-world problems and gain practical industrial experience, not so much to develop their knowledge and skills, but simply as a means of encouraging them to see themselves as engineers. This brings into play the notion of 'first order' (experiential, leading to the development of the transformative conception of learning) and 'second order' (academic, necessary for endowing students with certain facts and skills which are pre-requisites to engineering practice) knowledge [9], or 'direct' and 'mediated' learning [10].

Learning Styles.

Successful learning, however, is not simply a matter of defining the knowledge and understanding required. In engineering, like all disciplines, learning styles are vital in determining how well students learn. The paper will examine the range of learning styles described by Kolb [11] and their relevance to engineering education. There are two aspects to this. Students come to university with pre-existing learning styles, and we wish, to some extent at least, to encourage certain learning styles that match those of the profession/discipline. To what extent should we try to change students to fit the 'desirable' style, and to what extent should we cater to the diversity of styles?

Commonsense suggests that we should seek to accommodate each student's particular style, as a means for maximising the success and value of the learning experience for each student. Pragmatism drives us in the opposite direction and requires us to find a single, economical style of teaching, to fit an 'average' style of learning appropriate to

the discipline. This approach probably has a greater amount of wastage, where some students simply cannot resolve the mismatch between their learning style and the delivery of the subject matter.

Questions of preferred learning styles and the role they play in engineering education have been widely discussed, over a long period. For example [12] - [15] all address this topic.

A number of related questions spring to mind, for example:

- Am I teaching in a way that most closely fits the typical learning style of my discipline?
- If so, am I therefore encouraging the 'natural selection' of the most suitable students for the discipline?
- If not, am I causing an unacceptable degree of wastage of students who are, in fact, well suited to the discipline, and selection of students who are not?

Thus learning style is a vital factor in determining how well students learn, but the question of how learning styles are accommodated in a discipline remains open to debate.

Non-Cognitive Factors.

Students will learn well if: (a) they are motivated to do so, (b) they are happy, (c) they are having their needs met, and so on. This essentially humanist aspect of learning [16] encompasses many important factors which may, nevertheless, be overlooked in the focus on content, learning styles, etc. Non-cognitive factors are largely left to chance in engineering education.

Formal Theories of Learning and Engineering Education.

Key learning theories (Behaviourist, Cognitivist, Humanist and Social Learning) are summarised by Merriam and Caffarella [17], who add additional insight through their identification of the role of the teacher, and other key aspects of each theory. This paper argues that all four theories should govern a set of core beliefs and practices for engineering educators. The paper distinguishes, however, that, unlike Ramsden [18] it does not promote a view that subscribes to a melding of 'informal' and formal theories of learning. This paper argues that the 'indeterminacy of teaching in higher education' is probably the result of too little application of formal theories, and training in formal theories, despite any shortcomings that formal theories might possess in practice.

The sections which follow briefly outline the relevance of each of the main formal theories to a set of core beliefs and practices for engineering education.

Behaviourism.

Elements of engineering education, particularly in early years, require an approach that seeks to change student behaviour through the strengthening of responses to

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certain stimuli. Further, as engineering educators, we desire that the responses thus developed are transferred to other like situations. Engineers must have a level of competency in certain basic skills, for example soldering, for electronic engineers, which is most readily developed in a behaviourist environment. Teaching a skill like soldering also admits many of the features of behaviourism described in the literature. These include, active learning, repetition, positive feedback, and the freedom to develop the skill without fear of failure.

There is also a socialising aspect to this approach, and an opportunity to reinforce the kind of social behaviour desired in engineers, in addition to professional skills. For example students are conditioned to adopt certain safety procedures, in a behaviourist manner, while they are learning to solder.

Cognitivism.

As students mature in a Degree the cognitivist theory of learning becomes more representational of the processes and features of their learning. The manner in which the more senior student 'comes to see the solution after pondering a problem' [17] is typical of this holistic, internalised theory. This theory should hold interest and attraction for engineering educators because of the influence which they, as lecturers, might have on the content of the learning activity and how this might impact on the cognition of the content.

While this theory has been identified with the more experienced and senior student, who typically has a higher internal locus of control, the cognitive approach also influences teaching at all stages of a Degree. This theory holds immediate importance for styles of teaching, and especially, the style of presentation of learning content.

Humanism.

Maslow's [16] hierarchy of needs, at the centre of this theory of learning, holds particular interest for engineering education. Self-actualisation plays an important role not only in the education of engineers, but in the decision to undertake an engineering Degree. It is suggested that many engineering students undertake study in this discipline because they seek to have an impact in the world. Unlike many non-vocational degrees, the engineering student has at least some understanding of what they will be, and do, when they complete the degree. The humanist theory of learning then plays a role in achieving the transformation identified as a feature of successful learning, in the first section. Lecturers have a role to play here by ensuring that students develop more than just the narrow, subject-based skills. Humanism places a responsibility on lecturers to develop a relationship more akin to that of master/apprentice with students.

Social Learning.

The most striking feature of the social theory of learning is the influence that may be exerted by lecturers as a mentor, role model and guide. This theory becomes especially prominent in the last phase of an undergraduate engineer's studies. In fourth year, engineering student typically undertake a major design project. This may involve significant interaction with external customers. It is also the student's first

opportunity to operate in a 'professional' context, before graduating. Lecturers should actively seek to mentor such students, and to inculcate students with the standards of professional behaviour that will be expected of them in industry. It is in this phase of study that students have the opportunity to work with staff (as opposed to "for" them) and gain the confidence to take their place in the working world as a skilled, albeit inexperienced, professional. This is possibly the most neglected theory of learning, at the stage indicated, relying as it does on the strength of personality of the lecturer.

Constructive alignment

Educational theory recognises that learning in higher education must increasingly focus on teaching for understanding, especially in an era of globalisation and diversification of student ability. Before *teaching for understanding*, however, it is necessary to identify the nature of the knowledge in engineering programs.

Knowledge comes in a various forms. Biggs [4] defines 'functioning' or 'professional' knowledge. This kind of knowledge requires a foundation of 'declarative' knowledge (knowing *what*) and also involves 'procedural' knowledge (knowing *how*) and 'conditional' knowledge (knowing *when* and *why*). A clear understanding of the relationship between these different kinds of knowledge is an important part of establishing of the curriculum objectives for a course.

Not only must an instructor explain the details of the curriculum objectives of a program of study, he/she must also emphasise that learning in engineering is more than simply meeting those objectives. This outcome may be achieved through what Biggs [4] refers to as *constructive alignment*. In other words: (a) the curriculum objectives must express the details of the knowledge to be gained by the students, (b) the teaching and learning activities must express what will be done to achieve the objectives, and (c) the assessment tasks must tell students how they must demonstrate their level of understanding.

Summary

The *discipline* model is proposed as one of the reflective elements to fill the gap between individual and institutional elements. The combination of these elements had been lead to a complex model of quality in high education. The examples of the relationships between those elements have been provided.

This paper draws the threads of knowledge, understanding, learning styles and non-cognitive factors together under the umbrella of applicable pedagogical theories: behaviourism, cognitivism, humanism and social learning. The impact of these theories on successful learning in engineering has been examined. This paper proposes combining these theories into a single, hybrid theory for engineering education – a model for successful learning in engineering education.

This paper has described the model of the three holistic combinations of : (a) achievement of expected outcomes in individual courses, (b) achievement of expected outcomes for the whole program, and, (c) achievement of 'Graduate Qualities' in the concept of the reflective *discipline* for successful learning in engineering education.

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