A control systems approach to improving final year engineering students' conceptual and contextual grasp of dynamic systems

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Introduction

Well reported difficulties in engineering education throughput and retention (Fisher 2011), as well as complaints of graduate inability to 'apply knowledge' or demonstrate the necessary technical competence have led to a range of initiatives to both understand the difficulties as well as improve engineering education. The 21st century sees increasing complexity in the nature of engineering work. The UNESCO (2010) definition highlights the relationship between Science, Technology, Nature and Society. These complexities have implications for engineering educators, particularly those working with technologies and systems characterised by dynamic and exponential development, specifically control technologies. Educators have a responsibility to respond effectively to a changing technological landscape if we are to improve our graduate performance. This paper presents a curriculum review and implementation process - drawing on theoretically-informed tools from the sociology of education - designed to improve students' conceptual and contextual grasp in a process engineering qualification.

Context

The module under investigation is Process Control, presented to final-year Chemical Engineering students at a traditional university in the Western Cape, South Africa. The overall aim is to teach students how to design control systems and evaluate their performance, for single and multiple input-output systems. Such a curriculum is dependent on students' grasp of modelling and optimization concepts which have been covered in preceding modules. A major challenge is the integration and application of these concepts in a system design project.

The module has evolved over five years, and consists of traditional lectures, interactive computer-lab sessions, tutorials focussing on worked examples, and a practical laboratory session. Assessment consists of semester work (a practical report and five assignments), and two summative assessments: a mid-semester two-hour test and an end-semester three-hour test, both taken in a computer lab. From past experience, observed student difficulties include the understanding of the physical/concrete meaning of dynamic system models; the interplay between the physical system, its schematic representation, the algorithmic representation and approximated mathematical form; and insufficient skill in the use of programming languages for simulating control systems. For the lecturer, difficulties include balancing quantity versus depth; design and timing of a plantwide control design assignment; efficient use of lecturer and student assistant time; and constraints on availability of resources, such as the preferred programming language not being available to students for working at home and limited seating available in computer labs. In order to better understand and address these challenges, a project was undertaken to analyse the curriculum from a theoretically-informed perspective and adopt a new approach to the major project for the module.

Theoretical framework

Legitimation Code Theory (LCT) (Maton 2013) has emerged as a significant set of theoretically-informed tools to analysis and understand knowledge and practices. LCT Semantics has been used in a number of engineering studies (Blackie 2014; Wolff & Luckett 2013; Wolmarans 2016) and is concerned with ways of making meaning that connect abstract ideas to concrete applications so as to enable effective and 'cumulative' learning - learning that enables students to connect and extend concepts. Weak semantic gravity refers to a concept that transcends a particular context, and strong semantic gravity means something is dependent on a particular context. Semantic gravity (SG) offers an ideal tool to analyse levels of abstraction in engineering theory/practice. There are significant differences between the formulaic expression of a particular concept and its schematic representation or practical application. These multiple layers can be seen as representing a 'semantic range'. A curriculum needs to embody a semantic range in such a way as to enable cumulative learning.

Methodology & Findings

The first phase of the research project involved a breakdown of the sequential curriculum, with detailed examples of different levels of abstraction. The analysis - using a specifically designed *semantics* translation device – demonstrates the semantic range of the course as a whole, and the focus for the different teaching and learning activities.

Table 1. Process control study *semantics* translation device

Level descriptors	Semantics continuum	Levels of Abstraction	Process Control examples of SG levels	Previous course structure		Revised structure
				Lectures Wk 1 - 10	Project Wk 11 - 13	Lectures & Project Week 1 - 13
Theoretical Abstract	Weak SG (Context Independent)	L1	**Conservation** of mass & energy principles; **Control** principles: measure and manipulate	LECTURES	Plant-wide Control System Design	Lecture
	↕	L2	**Mathematical expressions** of process system (conservation of mass & energy) and control principles	TUTORIALS		Tutorial
		L3	Block diagram **schematic** of process and control systems	PRACTICALS		Plant-wide Control System Design
	Strong SG (Context Dependent)	L4	**Simulation** of process and control systems			Practical
Practical Concrete		L5	**Physical** process and control systems			

A control systems approach to the analysis – where the student learning experience *system* is a mirror of *the system* they are trying to learn - led to a revised curriculum delivery structure, with theory and practice scaffolded through the major project. Data were gathered from pre-assignment questionnaires, assessments, student interviews and feedback. Results suggest:

- Students struggle with the translation of L3 to L4 abstraction: successful programmatic implementation of control system representations.
- A small group of students show better performance in L4 than L3 (successful simulation without successful control system representation). Interviews confirm that they rely on pattern recognition of previous examples, rather than conceptual understanding.
- The design project starts with L4 (simulation) as entry point, and students move up and down levels of abstraction based on assessment requirements. Feedback suggests that repeated experience and practice with the simulation (L4) have helped with the physical interpretation (L5), as well as the underlying concepts (L1 to L3). This suggests that the careful design of an entry point into the hierarchy of abstraction is vital.

References

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