Informing engineering education for sustainable development using a deliberative dynamic model for curriculum renewal

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Abstract: Literature from around the world clearly suggests that engineering education has been relatively slow to incorporate significant knowledge and skill areas, including the rapidly emerging area of sustainable development. Within this context, this paper presents the findings of research that questioned how engineering educators could consistently implement systematic and intentional curriculum renewal that is responsive to emerging engineering challenges and opportunities. The paper presents a number of elements of systematic and intentional curriculum renewal that have been empirically distilled from a qualitative multiple-method iterative research approach including literature review, narrative enquiry, pilot trials and peer-review workshops undertaken by the authors with engineering educators from around the world. The paper also presents new knowledge arising from the research, in the form of a new model that demonstrates a dynamic and deliberative mechanism for strategically accelerating for curriculum renewal efforts. Specifically the paper discusses implications of this model to achieve education for sustainable development, across all disciplines of engineering. It concludes with broader research and practice implications for the field of education research.

Context

Engineering education has come a long way over the last two centuries, rising to the challenge of a series of periods of rapid change and upheaval such as the industrial revolution in 18th Century Britain and the two world wars of the 20th Century (Perkin, 2007). Industrial society and in particular economic demands of the first half of the 20th Century required the invention of modern research and teaching universities and technical colleges. By the end of the Second World War, engineering had become a core profession and a core part of the higher education curriculum, equipping professionals to deliver goods and services in the face of ever-increasing demand across an expanding spectrum of needs. The curriculum has evolved to follow the development of society and industry in order to continue to meet its needs, comprising a complex and highly specialised curriculum. A schematic indicating the progress of these impetuses, or ‘waves of innovation’ as documented by Smith and Hargroves (2005) and based on the work of economist Joseph Schumpeter in the 1940s is shown in Figure 1. Overlaid on the diagram is a sketch of the capacity building transitions associated with these waves, which the authors have generated from the literature and refined through subsequent peer-review by senior engineering educator researchers in the field.

The fifth wave of innovation, which occurred towards the end of last Century, provided a new technological platform and numerous tools for enhancing communications, computation, design, drafting, and data analysis and storage, allowing operations to be significantly improved, and transaction costs to be significantly reduced. However the legacy of this wave is that it has come with
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an environmental impact that is now becoming evident and beginning to impact on economies and industries (Hargroves & Smith, 2005; Smith et al, 2010; Brown, 2010; Stern, 2006). Subsequently society now faces a host of emerging challenges and opportunities such as reducing greenhouse gas emissions, addressing climate change adaptation needs, dealing with resource scarcity and creating sustainable solutions that decouple economic growth from negative environmental pressure.

In the sixth wave, society is responding to these emerging challenges, with innovations that both build on the previous waves and also significantly reduce environmental pressures (Weizsäcker et al, 2010; Birkeland, 2010), including substantial new knowledge and skill sets across all engineering disciplines in new areas such as resource productivity, energy efficiency, whole system design, and biomimicry - design inspired by nature. Within this context, the system of engineering education faces a significant challenge to provide graduates that can assist industries to reduce such impacts and remain competitive and productive. Indeed, compelling evidence suggests that the emerging imperative for the next decade will be to rapidly embed education for sustainability (EfS) within all education programs, including engineering as a priority (Concoran & Wals, 2008; Jones et al, 2010).

However, research findings from around the world indicate that, to date, the integration of significant new knowledge and skill sets within higher education is limited and at best ad hoc (for example UNESCO, 2009; RAE, 2007; AASHE, 2010; King, 2008; Wals, 2008) and the traditional time to undertake a full-scale curriculum transition (in the order of two decades) exceeds the available window for equipping professionals with critical new graduate attributes; a significant time lag dilemma’ facing educators (Desha & Hargroves, 2009). Furthermore, within the literature (for example see Heywood, 2005), there are few examples of systemic curriculum renewal that meet the recommended timeframe of one decade, or discussion of how curriculum renewal could be undertaken over such contracted timeframes.

**Research Questions**

From the literature review findings, it is clear that a process for curriculum renewal is needed to transition engineering education from ‘old industry’ to ‘new industry’ practice. As highlighted in Figure 2, this process does not need to be the new ‘norm’ for curriculum renewal processes, but rather a transitional measure, intended to address the time lag dilemma facing higher education. There is an absence of guidance on how to undertake curriculum renewal in a manner that is informed by the
surrounding context. Hence, there is a need to improve the process of curriculum renewal to ensure that academics undertake a systemic approach to considering emerging waves of innovation, associated knowledge and skill areas, internal staff capacity, and opportunities to engage with real projects happening on campus and in the community.

Within this context of curriculum renewal theory, the authors sought to provide guidance for academics considering rapid curriculum renewal in urgent and challenging times. Specifically, the authors asked ‘How can sustainability knowledge and skills be effectively embedded into curriculum?’, and further, ‘What can be done to accelerate the process?’ It is considered that these questions are of critical importance to engineering education, given the lack of progress to date in systemic and timely curriculum renewal.

![Figure 2: An illustrative curriculum transition curve, showing a period of rapid curriculum renewal from ‘old’ to ‘new’ industry](image)

**Theoretical Framework**

The theoretical framework for this study was created by finding commonality within the fields of sustainable development science, engineering education and curriculum renewal processes. Ultimately the process of reflexive inquiry provided a supporting role to the literature reviews, which collectively informed the model for rapid curriculum renewal outlined below.

**Methodology**

Given the flexibility in method permitted by researchers such as Denscombe (2007), Layder (1998), and Denzin and Lincoln (2003), this research adopted a relatively unorthodox mixed method through an adaptive and interpretive approach that is situated within a qualitative research paradigm. The research design was iterative and involved multiple methods, drawing from the perspectives of both the ‘armchair theorist’ (i.e. a situational analysis of what is happening to engineering education and why, and considering important elements for curriculum construction) and field-based researcher (i.e. consideration of past and current action within the professional community, indicating emerging professional needs that potentially should be captured in the curriculum reconstruction process).

This approach fits in well with Layder’s continual refinement perspective on qualitative research, where elements taken from existing problematics can, when reorganised and examined in a new order, result in much greater clarity and understanding. The use of multiple methods can also contribute to producing such enhanced clarity with regard to the nature of the problem, the state of engineering education for sustainable development, and mechanisms to address timely and systemic renewal.

This research used three main sources of data:
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- Literature from educators describing their experiences and evolving theories, using historical and ethnographic research methods.
- Personal narrative of the authors’ previous project experiences, using reflexive inquiry (i.e. personal review) to undertake document analysis and archival research using content and thematic analysis.
- Peer review from experts in the field regarding the findings from those experiences, to triangulate data sources.

**Major Findings**

The research explored the need for sustainable development knowledge and skills to be embedded within curricula, especially within engineering education. In this case, personal experience suggested a shortfall in engineering education for sustainable development (EESD) and subsequently an urgent need for curriculum renewal.

An integrative literature review of curriculum renewal literature was used to ask whether there was any discourse or inquiry within this literature of the elements of curriculum renewal. From this literature review it was concluded that despite evidence of frustration with the current ‘slow’ process, there is an absence of documented discourse about actually addressing these potential time constraints, and no alternative is discussed. Indeed, discussions of timing issues are found to have existed for over four decades in the literature, and although the field is focused on the issues of systematic curriculum design and development, it was concluded that there is little consideration for the speed at which curriculum is constructed and implemented or reviewed. While existing models provide significant guidance on systematic curriculum construction, none consider – either explicitly or implicitly – how to vary the pace at which curriculum renewal may be undertaken.

**Emerging Elements of Curriculum Renewal**

It was hypothesised from the literature review that if there are emergent processes that have not yet been captured in systemic considerations of rapid curriculum renewal, then they should be evident in documented experiences of curriculum renewal. Subsequently EESD literature was reviewed with regard to how rapid curriculum renewal was attempted. It was concluded that there are a number of mechanisms, which could be grouped under a number of themes or ‘elements’ of curriculum renewal. Secondly, higher education literature was reviewed to learn from other professional discipline experiences including law, business, nursing and medicine, where curriculum had clearly been renewed in urgent and challenging times. A process of formal reflective inquiry was undertaken into the authors’ personal experiences in attempting curriculum renewal as an educator and researcher including case studies, pilot trials, and a series of exploratory workshops with engineering educators from around the world to further inform the literature findings. This included reinforcing or contradicting aspects that were already discussed in the literature, and uncovered supporting evidence that was not apparent in the existing literature.

This multi-method exploratory process resulted in the distillation of a set of elements evident in time-managed curriculum renewal processes, which extends the discourse on ‘curriculum in context’. These include:

- A whole-of-institution curriculum renewal strategy;
- Identification of preferred graduate attributes;
- Mapping of learning outcomes to form learning pathways across programs;
- Assessment of the level of coverage in existing programs (Desha & Hargroves, 2007);
- Developing and updating units, including integrating on-campus and in-community experiences;
- Implementation of updated units throughout program (Paten et al, 2005);
- Staff awareness raising and capacity building;
- Internal and external collaborations, including bridging and outreach activities; and
- Monitoring and evaluation to ensure continual improvement.
Emerging Model for Dynamic and Deliberative Curriculum Renewal

Following extensive development and trialling of a number of elements of curriculum renewal the authors sought to develop a schematic that could demonstrate how these elements could be harnessed to provide a strategic approach to curriculum renewal. This enquiry included analysing a number of earlier models by leaders in the field over the last half century, including Tyler (1949), Taba (1962), Wheeler (1967), Kerr (1968), Walker (1971), Stenhouse (1975), and Egan (1978). It was concluded from this analysis that there is a lack of iteration and systemic dynamism within existing models. Previous models highlighted the importance of various aspects of systemic curriculum renewal, such as forward planning, review, the end-user and consideration of the wider context for learning. However, there was not a whole of system schematic that highlighted the importance of front-end loading the process or the iterative and consultative aspects of curriculum renewal.

Considering this identified gap in conceptualisation, the authors have developed a whole of curriculum interpretation. The resultant circular schematic shown in Figure 3 provides the sense of non-linear dynamism while also demonstrating the need for a deliberative approach informed by a number of factors at each stage of the process. It is intended that the model provide an accessible and useful tool for engineering academic staff to review and update their units, courses and programs.

**Figure 3: The Desha-Hargroves Deliberative and Dynamic Model for Curriculum Renewal**

Beginning with the curriculum renewal strategy text in the centre of the diagram, the model highlights the importance of having a central point of reference when undertaking systematic curriculum renewal, particularly when multiple educators are involved. The arrows immediately around this text are a reminder that the strategy needs to inform each and every stage of curriculum renewal. In the five larger circles around the central strategy, the five key steps in curriculum renewal are linked in an iterative process that requires a substantial amount of planning and investigation before the individual units are revised. The arrows interacting with the outer circle are a reminder that this stepped process requires continual monitoring and evaluation, internal and external collaboration, and awareness raising and capacity building among staff. Furthermore, the steps are informed by, and also inform, the three activities in the outer circle.
**Recommendations & Future Research Plans**

In considering potential application of this model for curriculum renewal, it is clear that there are still few catalysts that are large enough to drive substantial curriculum renewal in engineering education. Considering the case of engineering education for sustainable development, it is difficult to predict when the trigger for such renewal will occur globally, but the literature suggests that market and regulatory requirements for sustainability related capabilities will likely escalate within this decade.

With such timeframes in mind, this model may be slightly pre-emptive of a mainstream shift to systemic curriculum renewal towards education for sustainability. However it does provide a useful context and framework for considering how such curriculum renewal might occur once a decision is made to proceed. It also highlights the opportunity for graduate attribute development, mapping and auditing to add value to any existing curriculum renewal process, prior to beginning unit review and development. Further to the development of this model, future research plans will focus on systematically trialling and further elaborating its components and their interaction.

**References**


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