The Role of the First Year Engineering Experience in Curriculum Redesign

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Abstract – **The First Year Engineering Experience seeks to reduce student attrition rates by providing students with orientation, study skills, motivation and other experiences that will enable them to survive in, and ultimately graduate from, engineering programs. The central argument of this paper is that the comprehensive redesign of undergraduate curricula can yield much greater benefits. The paper presents discussions of why comprehensive redesign is needed, how the processes of redesign can be approached, and the potential impact that curriculum redesign may have on the First Year Engineering Experience. Two predictions of the work are that there will be significant diversity among redesigned curricula that emerge at different institutions, and that the First Year Engineering Experience will play a pivotal role in the implementation of redesigned curricula.**

Index Terms – ABET, Accreditation, Curriculum Redesign, Cognitive Development, First Year Engineering Experience, Student Development Model.

INTRODUCTION

The author teaches several sections of *ECS 1200 - Introduction to Engineering and Computer Science* at the University of Texas at Dallas. ECS 1200 is a required course that is taken by approximately 600 freshmen. The goal of the course is to reduce student attrition by equipping students with institutional and professional orientation, study skills and motivation that will help them to make successful transitions to college. Similar 'student development' approaches are used in many courses that form part of a First Year Engineering Experience (FYEE). A comprehensive framework for such courses has been developed by Landis [1].

Many FYEE initiatives have a broader scope that includes discipline-specific technical content, introductory material on design processes and project management, and the exercise of newly acquired skills in the context of team-based projects. Some integrated, year-long sequences result in the execution of ambitious engineering projects. However, the underlying goal normally remains that of helping students to adjust to the expectations of traditional engineering curricula.

Amending the first year curriculum in order to bridge the gap between incoming students and the demands of traditional curricula provides significant benefits. However, redesigning entire curricula can provide greater benefits. The purpose of this paper is to present perspectives on the redesign of engineering curricula and the impact that redesign may have on the First Year Engineering Experience. Specific topics that will be covered include:

- Limitations of Traditional Curricula
- Impediments to Curriculum Redesign
- Procedures for Curriculum Redesign
- Cognition-Driven Education

Two conclusions of this study are that there will be significant diversity among the redesigned curricula that emerge at different institutions, and that the First Year Engineering Experience will play a pivotal role in the implementation of redesigned curricula.

The author's views on undergraduate education were influenced by experiences that were gained during an NSF-funded curriculum restructuring project [2]. Some details of this project are provided in an Appendix.

TRADITIONAL CURRICULA

In traditional undergraduate curricula, the first two years of study focus on professional preparation in mathematics, the sciences and the humanities. This is known informally as the 'sink or swim' approach. Traditional curricula worked adequately well for several decades and became enshrined in accreditation requirements. They became less effective as time passed. This was due to various factors that include the declining levels of preparation of incoming students and the continuing expansion of scientific and technical knowledge. Manifestations of problems include high rates of student attrition and negative feedback from employers regarding the skills, attitudes and expectations of graduates.

ABET's Engineering Criteria 2000 responded to the limitations of traditional curricula by "shifting the basis for accreditation from inputs, such as what is taught, to outputs—what is learned" [3]. In addition, "new criteria specify 11 learning outcomes and require programs to assess and demonstrate their students' achievement in each of those areas" [3]. Many worthwhile responses to the limitations of traditional curricula have emerged since the accreditation procedures were changed. However, these have mostly been 'point' solutions rather than 'systemic' solutions. Reasons for this are discussed in the next section.

IMPEDIMENTS TO CURRICULUM REDESIGN

Viewed from the perspective of organizational behavior, the redesign of curricula appears very difficult. Institutional cultures rank the relative importance of academic activities in a hierarchy that typically places the acquisition of research funding and the publication of research findings at the top, and the supervision of undergraduate laboratories and teaching freshmen and sophomores at the bottom.

The systematic neglect of freshmen and sophomores can be seen as a pragmatic response to resource limitations. When implemented well, freshmen and sophomore classes involve a combination of large scale and 'high touch' needs that can overwhelm available resources. Departments of engineering respond to this situation by shipping their freshmen and sophomores off to other departments and then devoting resources to 'educating the survivors.' Departments in other colleges are willing to teach large 'service' courses in order to justify staffing levels but seldom teach the courses in ways that develop engineering skills.

There is a mismatch between the educational needs of incoming students and the backgrounds and skills of most engineering faculty. Foreign-born faculty members (such as the author) who received a secondary education in systems that are academically more demanding may be poorly calibrated to the skills and mindsets of recent high school graduates. In addition, very few faculty members receive training in teaching at any level, and many have never worked in industry. Such backgrounds make it difficult to teach incoming freshmen, many of whom respond poorly to the didactic styles that some professors use because it is how they were taught.

The redesign of curricula will be difficult, but the waste of human and economic potential associated with the use of traditional curricula is unsustainable. Declining levels of preparation of incoming students are not likely to improve; they are boundary conditions that will impact the process of curriculum redesign. The skills that are valued by the employers of graduates will not be relaxed but will become target outcomes of curriculum redesign. In the remainder of this paper, it will be assumed that the radical redesign of undergraduate curricula is inevitable.

PROCESSES OF CURRICULUM REDESIGN

The redesign of a curriculum will involve phases of preparation, design and implementation. The preparation phase will seek to answer questions such as:

- What knowledge, skills and attitudes do incoming students possess?
- What new knowledge, skills and attitudes need to be imparted to students?
- How will the new knowledge, skills and attitudes be imparted efficiently?
- What institutional and other factors constrain the process of curriculum redesign?

The answers that emerge from the preparation phase will reflect local factors. There will therefore be diversity among the curricula that emerge from different institutions.

The design phase can be viewed as a process of constrained optimization that maps answers from the preparation phase onto academic pathways. The implementation phase will need to proceed in ways that are incremental and iterative, in order to allow for mid-course adjustments and adaptation to changes in goals and constraints. The processes of preparation, design and implementation will have political, as well as analytical, aspects. Being able to make and implement decisions in a timely manner will be very important. Environments that feature multiple levels of slow-moving bureaucracy will inhibit, and in some cases prevent, meaningful redesign.

Departments of engineering will eventually be reorganized in ways that support redesigned curricula. This may involve the formation of academic sub-units that are led by Professors of Practice. It will also involve more use of full-time lecturers who will not need Ph. D.'s, providing that they have industrial experience and can teach, mentor and motivate freshmen and sophomores. These trends are already starting to emerge.

Content delivery methods will be an important aspect of curriculum redesign. The role of the 'sage on the stage' will become less central and the use of active learning techniques will become more pervasive. This will involve diverse strategies such as flipped lectures and an increased reliance on team projects and peer assessments. After the basic calculus sequence has been completed, science and mathematics will be provided on a just-in-time basis that is motivated by engineering applications.

COGNITIVE DEVELOPMENT

Processes of curriculum redesign need to be driven by consistent views of the underlying problems and of effective ways to address them. A long-standing criticism of K-12 education in the United States is that there is 'insufficient time on task.' Critics point out that the school year is shorter than in other developed countries, and that far less time is devoted to mathematics and science. Although such inter-system comparisons are accurate, they do not explain the steady decline over time of the levels of preparation of high school graduates educated in the United States.

Alan Cromer has pointed out that the modes of scientific thought are very different from the modes of every day thought, and that this means that scientific and technical education faces uniquely difficult challenges [4, 5]. Lewis Wolpert has made similar observations [6]. Cromer argues that declines in the levels of student preparation are due to the use of constructivist educational principles that impede the development of higher-level cognitive skills. Constructivists view humans as [7] "observers, participants, and agents who actively generate and transform the patterns through which they construct the realities that fit them." Unfortunately for the application of this view to science education, it took more than 2000 years after the death of

Aristotle before "observers, participants, and agents" such as Galileo and Sir Isaac Newton "constructed the realities that fit them" and initiated the modern era of science. It is unrealistic to expect middle- and high-school students to replicate spontaneously the achievements of Galileo, Newton and other scientists.

Cromer argues that successful students progress through identifiable stages of cognitive development, and that a central purpose of education is to facilitate and accelerate this journey. Cognition-driven education directs attention to the higher level cognitive skills that determine professional effectiveness. It also illuminates the danger of allowing students to plateau prematurely at the level of small-scale analysis. Cromer's philosophy is not completely original. The general underpinnings of cognition-driven education were established more than 50 years ago in Bloom's Taxonomy of Learning Domains [8], and many articles have been written on the role of cognition in science education. A typical example is a paper by Redish [9].

The redesign of engineering curricula will almost certainly be cognition-driven. The asynchronous transfers of discipline-specific knowledge that occur in a traditional curriculum will be replaced by a more integrated curriculum that moves students along progressive stages of cognitive development. Pressures associated with the expansion of technical knowledge will be ameliorated by the adoption of a 'Core and More' structure in which the first two years of a curriculum cover a core of knowledge that all engineers within a discipline are assumed to have mastered. This may be structured as a 'Pre-Engineering' program. The third and fourth years will feature specialization within one or two areas of concentration. Having achieved higher levels of cognitive development, and having learned how to acquire and deploy specialized knowledge, graduates will have more confidence in their ability to acquire additional knowledge in their jobs.

It will be important to recognize distinctions and differences between science education and engineering education. Engineering focuses on the application of knowledge. Many of the skills associated with applying knowledge are acquired efficiently through active learning techniques that, ironically, are often associated with previously-criticized constructivist educational principles. Engineering educators will need to draw a careful distinction between the benefits and the pitfalls of constructivism. Cognitive development can be (and should be) reinforced by active learning!

FIRST YEAR ENGINEERING EXPERIENCE

The analysis presented in this paper suggests that the redesign of an undergraduate curriculum needs to occur at one level of abstraction before the design of an institutionally appropriate FYEE is undertaken at the next level of detail. The role of the FYEE is likely to evolve and expand from that of providing a set of knowledge, attitudes and skills that can increase retention rates to that of guiding students through the first phase of a multi-year journey of cognitive development and skills acquisition.

The abrupt introduction of a redesigned curriculum is neither feasible nor desirable. A more effective, inherently incremental implementation strategy will start with the FYEE and then proceed via a multi-year process of diffusion, with ongoing assessment, evaluation and adjustment. This strategy will have a natural time scale of four years as a freshman class progresses to graduation. Faculty buy-in may occur incrementally over time as a result of student expectations and as the initial stages of implementation are recognized as being effective.

In summary: the *design* of a FYEE needs to occur at a relatively late stage of the redesign of a curriculum, but the *implementation* of a FYEE is the natural first step in an implementation strategy that is slow enough to be accepted but fast enough to be completed.

CONCLUSIONS

There is an urgent need for the comprehensive redesign of engineering curricula. The process of redesign can be driven by models of cognitive development. The detailed structure of a redesigned curriculum will reflect factors that are institution-specific. The roles of the FYEE will be to lead students through the first portion of their journey of cognitive development, and to be the platform for the initial stages of the incremental implementation of the redesigned curriculum.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge useful discussions with Professor David Scott of Northern Arizona University, and with Professors John Cole, John Hansen, Simeon Ntafos, and Janelle Strach of The University of Texas at Dallas.

REFERENCES

[1] Raymond B. Landis, *Studying Engineering: A Road Map to a Rewarding Career*, 4th Edition, Discovery Press, 2013

[2] David P. Scott et. al., Systemic Thread-Based Adaptation of an Electrical Engineering Curriculum, NSF Project No. 0343297, Contract period 09/01/2003 – 08/31/2005, work performed at Northern Arizona University.

[3] http://www.abet.org/engineering-change/

[4] Alan Cromer, *Uncommon Sense: The Heretical Nature of Science*, Oxford University Press, 1993

[5] Alan Cromer, *Connected Knowledge: Science, Philosophy and Education*, Oxford University Press, 1997

[6] Lewis Wolpert, *The Unnatural Nature of Science*, Harvard University Press, 1994. First published by Faber and Faber, London, 1992

[7] http://en.wikipedia.org/wiki/Constructivism_(learning_theory)

[8] http://en.wikipedia.org/wiki/Bloom's_Taxonomy

[9] Edward F. Redish, "Implications of Cognitive Studies for Teaching Physics." Am. J. Phys., vol. 62, pp. 796-803, 1994

APPENDIX: THE NAU RESTRUCTURING PROJECT

While working at Northern Arizona University (NAU), the author participated in the definition and the implementation of an NSF-funded project [2] that investigated ways to restructure an undergraduate curriculum in electrical engineering. The project was facilitated by the small size and undergraduate focus of the department. All six faculty members had industrial experience as well as Ph. D.'s, and five of them participated in the restructuring project. All undergraduate classes were taught by regular faculty, and class sizes were small (typically 25-30 students in the junior-level core courses.) The institution valued innovation in education and imposed comparatively little bureaucracy.

The restructuring project involved a combination of project-wide themes and initiatives that were championed by individual members of the faculty. The themes included 'More Engineering, Sooner' and 'Context, Hierarchy and Structure.' The author's personal initiatives were 'Universal Development Methodology' and 'Flex Labs.'

More Engineering, Sooner

The heart of the project was an explicit rejection of the idea that engineering students need two years of preparation in mathematics and science before they can do significant amounts of engineering. Students who want to become engineers should start doing engineering right away, and students who will discover that they do not want to become engineers should do so quickly! It was fairly easy to add significant amounts of engineering to the first two years of the curriculum, partly by deferring the completion of some humanities requirements to the junior and senior years.

Context, Hierarchy and Structure

If good engineering judgment comes in part from 'having the big picture,' then engineering faculty should seek to convey the big picture! Instructors handle this differently. The author likes to structure the first lecture of a course as a relatively high-level *prospective* lecture (an outline of what will be learned, how and why it will be useful, how the subject area is structured, and how it relates to the rest of the curriculum); and to structure the final lecture of a course as a *retrospective* lecture that integrates the material, emphasizing how far students have come and how they can build on their accomplishments. Core concepts and inter-relationships are reinforced in lectures, homework assignments, laboratory sessions, and exams.

Universal Development Methodology

This initiative provided a unified view of the processes of development and design plus opportunities to practice these approaches. The unified view is a model of development that emphasizes the hierarchical and iterative nature of different levels, from 'lore,' scaling and rules of thumb, through analytic theory, specially-written software tools, general simulation tools, experimental design, fabrication, characterization and assessment. Students are encouraged to view the essence of engineering as exercising the judgment needed to switch between levels in ways that lead to high quality outcomes with acceptable expenditures of time and resources.

Flex Labs

The main idea of Flex Labs is that different supplementary activities provide maximum incremental value at different times during a course. In the case of a junior-level electromagnetism course, the first two labs were devoted to math revision and practice (e.g. vector analysis and vector calculus); a mid-semester lab dealt with the mathematics of the wave equation; portions of some labs provided historical context; and students learned to use some simulation tools. The last four labs were occupied by a project that involved the simulation, design, fabrication and characterization of an antenna.

Assessment

Feedback received from students, employers and faculty was uniformly positive. The core themes and several of the initiatives became institutionalized in the curriculum. Some initiatives were successful but did not survive after a 'champion' either retired or changed jobs. In retrospect, it is clear that additional value could be obtained by adding a student development course of the type that has been developed by Landis [1].