The Lessons We Learn: Reflections on an NSF Engineering Education Coalition

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Engineering education is at a crossroads. The present paradigm of engineering education that evolved with the rise of the engineering sciences from the 1950’s is being questioned in the light of the rapid changes in technology and engineering practice, the increasingly complex demands placed on engineers by the society they serve, in a world of finite resources and environment imperatives. Over the past five years prototypes of new forms of engineering education have been developed under the Engineering Education Coalitions in the USA. An overview of the National Science Foundation (NSF) Coalition program and a profile of one of these, the SYNTHESIS Coalition are presented. The recurring themes are contextualisation, diversity, breadth, integration, new modes of delivery and cultural change. They point to the need for a new, inclusive paradigm of engineering education, one where the elegance of the engineering sciences is complemented by the richness of the art of engineering.

AT THE CROSSROADS

Over the past 40 years the engineering sciences have risen to assume their current dominant position in the ethos, structure and delivery of engineering education, first in the USA and subsequently in Australia. In the USA, design and other courses closely linked to professional practice have been decimated over this period. These elements have also been significantly reduced in most Australian curricula, causing an imbalance. Existing curricula and teaching practices will not adequately meet the changing needs, backgrounds and aspirations of our students; the reality of lifelong learning and the changing priorities of industry; increasing world competitiveness, globalisation, teamwork; communication, cultural and environmental sensitivity.

The Institution of Engineers, Australia recognises the need for engineers to be much more than technocrats, to be able to integrate human, social, economic and political factors into design and project work and to communicate this clearly to different groups. The Williams committee in their 1988 Review of Engineering Education in Australia state that:

"engineering schools have been more responsive to changes in engineering science and equipment than to changes or needed changes in engineering practice, and too little interested in the human element in technology [1]."

There is little evidence that meaningful changes have occurred in response to this observation. The Williams committee also concludes that Engineers have an importance in society out of all proportion to their numbers. Improving the quality of engineers through reform of engineering education is therefore of great national importance.

In the USA, the National Research Council sponsored a series of regional symposia drawing attention to major issues in engineering education including many themes most familiar to innovative engineering educators in Australia [2]. Can the mathematics/science preparation of students enter-
ing engineering study be strengthened? Can outreach to and retention of women and under-
represented minorities be improved? How can the education system continuously adjust to changing 
student demographics? Is the curriculum adequate? Are teaching methods appropriate? How can 
retention be improved? Is the four-year baccalaureate degree the best model? Is there a need for a 
practice-oriented graduate study? Should participation of foreign nationals be limited? Does the 
faculty reward system support the full scope of the institutional mission (teaching and research)? Is 
there sufficient diversity amongst engineering faculty? What are some avenues for continued 
professional development of faculty as both teachers and researchers? Given the rapid change of 
both technology and engineering practice, does the engineering education system adequately meet 
the continuing education needs of practicing engineers? Does the engineering education system have 
a responsibility to attempt to improve the technological literacy of groups such as school 
teachers, all students in college and university, law makers and the public? And the perennial: How can 
the public image and perception of engineering be improved?

Over the past five years, the National Science Foundation (NSF) in the USA has funded a series of 
Engineering Education Coalitions to pioneer new forms of engineering education. These coalitions 
are addressing many of the issues raised in the NRC report. This paper presents an brief profile of the 
SYNTHESIS Coalition as a means of exploring possible futures for engineering education in 
Australia. This case study was conducted under one of two inaugural National Teaching Fellowships by 
the Committee for Advancement of University Education (CAUT). Data was gathered from visits 
to six sites in the SYNTHESIS Coalition, interviews with the key participants and analysis of the 
reports and working documents of the Coalition. The paper commences with a brief overview of 
Engineering Education Coalitions.

ENGINEERING COALITIONS: EARLY VISIONS

The NSF established the first two Engineering Education Coalitions in 1990. The aim was to 
create coalitions amongst engineering schools that were diverse in their history and type (longstanding 
and relatively new; private and publicly funded), were geographically distributed, represented the 
range of possible missions (research university and teaching-based colleges), had different student 
demographics (predominantly white and Historically Black Colleges and Universities 
[HBCU's]) and consequently were unlikely to have had much prior contact. The concept was that the 
coalition members would draw on their diverse backgrounds and histories to share curricula, 
subjects, teaching delivery systems and practices for the mutual benefit of all, to challenge traditional 
ways and to create new ways of conducting engineering education.

The first to be set up were SYNTHESIS and 
ECSEL (Engineering Coalition of Schools in Education and Leadership). Both of these founding 
Coalitions were focused on design or in the broadest sense, Synthesis, to contrast with the 
analysis that had come to dominate most curricula.

The ECSEL philosophy was infusion of Design 
Across the Curriculum. This translated into design 
projects commencing in the first year that embodied 
social, political, environmental, ethical, financial, 
and technical considerations. There was to be a 
strong emphasis on hands-on experiences and a 
sensitivity to the individual students. New delivery 
methods including mentoring of junior students by 
advanced students and self-contained learning modules 
were proposed.

In 1992 a second pair of Coalitions, SUCCEED 
(Southeastern University & College Coalition for 
Engineering Education) and GATEWAY, were 
initiated. SUCCEED had a vision of a new 
curriculum, Curriculum 21, in a new academic 
culture. The new culture is founded on the 
principles of continuous improvement to ensure 
program quality and renewal. Notably, Curriculum 
21 is founded on an emphasis on both the process 
of engineering and the engineering education 
process. Their emphasis on process stems from a 
realisation that US success in competitive markets 
depends on efficiency and effectiveness in
innovation in new product development in industry. Graduates of such a program will be multifaceted technical integrators not technical specialists. An important goal in this is to reduce or eliminate artificial boundaries at the transitional interfaces and within the academic environment that prevent students and faculty from integrating course material and its application to engineering practice. Similarly, GATEWAY aims to shift the focus in courses to the broader experience in which individual curriculum parts are connected and integrated.

THE SYNTHESIS COALITION

The SYNTHESIS Coalition consists of eight member institutions; Cal Poly San Luis Obispo, Cornell University, Hampton University, Iowa State University, Southern University, Tuskegee University, and the University of California, Berkeley. It includes three private and 5 public universities, three HBCU’s, and spans many regions of the country. It incorporates a range of engineering disciplines including civil, electrical, and mechanical engineering. The Coalition has its headquarters at Cornell. The initial aim of SYNTHESIS was to develop bold experiments designed to guide the way to new and revolutionary ideas in teaching and learning in engineering curricula and the technologies to support these changes. The focus has been on Synthesis, attempting to create a new breed of engineer who is skilled in multi-disciplinary, open-ended problem solving and design within the context of broader societal factors. Central to this is the desire to increase dramatically the quality of US undergraduate engineering education as well as the number of engineering baccalaureate degrees awarded, especially to women, unrepresented minorities and people with disabilities. Existing curricula were seen as being very compartmentalised. The vision of the Coalition was the attainment of an integrated course structure across all subjects and all years of the undergraduate program.

The Coalition was initially funded over 5 years at US$15m to be complemented by donations of equipment from major computer vendors. Currently the Coalition is seeking a renewal of funding for a further five years. It has a Director, a management board whose members are drawn from the participating schools and it is supported by a small team of administrative staff based at Cornell. The bulk of the funding is used to support project proposals from individuals or teams of academics at the participating schools in the Coalition. These proposals must fall within the broad program of the Coalition and the funds are allocated on a competitive basis amongst the applicants. Individual projects are developed and evaluated at one of the schools and where possible deliverables are shared across other Coalition schools. One of the strengths of the Coalition is that individual initiative and effort are harnessed collaboratively around the shared vision of synthesis.

Initially the work of the Coalition was divided into four interrelated areas: curricular reform; pipeline; supporting technology; and linkage. Curricula would be reformed through alternative modes of instruction and access, including modular self-paced instruction. Due account would be taken of the context in terms of industry practice, historical trends and societal concerns and there would be integration between courses. These innovations were to be supported by the new information technology. Publisher John Wiley joined the Coalition to be a partner in creating the next generation of electronic teaching materials. The pipeline alludes metaphorically to the flow of students through the education system from kindergarten to graduate school. To reduce leakage from this pipeline four issues were addressed: outreach; retention; enrichment; and research into learning. Outreach is concerned about networking with students at primary and high schools and community colleges to give them a first-hand experience of the profession and of being an engineering student. A fascinating example of this is the Big Book - Not all Engineers are Train Drivers, a colouring book for first grade students. This engaging means of undermining a stereotype of engineers (in the USA) is typical of the enthusiastic approaches taken to pipeline. The Coalition is developing means to motivate and support and consequently retain at-risk students in engineering schools, especially women and minorities. The pipeline program also recognises differences in the preferred learning styles of individuals and the need to be culturally sensitive.

Computing and information technology are the prime enabling technologies for distributing and delivering the new curricular materials to staff and students. The most visible manifestation of this is the National Engineering Education Delivery System or NEEDS, described below. The curricula reform, pipeline programs and the enabling
technologies are integrated through the linkage program. It was envisaged that the Coalition would leverage off other initiatives in education reform and industry contacts in a multiplier effect as part of linkage.

Over the first five years of operation the foci of the Coalition have shifted as experience was gained with the implementation of the original vision. Given the scope of the original vision and the diversity of the participating institutions, this shift was inevitable. Currently the Coalition’s work in curriculum reform and innovation is concentrated in three metaprojects: Computer Integrated Civil and Environmental Engineering (CICEE) Curriculum, Mechatronics Systems Curriculum and Synthesis Systems Core Curriculum [3]. Together these comprise the Applications Team. This work is complemented by that of the Infrastructure Team, which is concerned with technological support for distribution and delivery of learning materials to faculty and students. It is not possible in a few pages to adequately describe all the facets of the Coalition. The following snap-shots give some insight into the range of activities in which it is involved.

SYNTHESIS METAPROJECTS

The CICEE metaproject operates within a relatively well established disciplinary environment. The innovation is in the use of computer-based instructional materials to integrate across the boundaries of traditional subjects taught in isolation and across the years of a course. Students are encouraged to recognise the commonalities in the processes of design and problem-solving throughout the course. An early example is the computer-based multimedia case studies in structural engineering. Case studies of significant engineering structures are presented as a series of slide images together with factual information on the function, components, and materials used. This is complemented by data on the historical and geographical context of the structure and brief biographies plus photos of the principal engineers and architects concerned. These case studies can be used by lecturers to prepare lecture presentations and as a resource for individual study by students. This multi-media presentation improved students’ visualisation, reinforced their understanding of engineering terminology and impacted on their attitudes and ethical values [4].

Mechatronics as adopted by SYNTHESIS is broadly defined as the application of complex decision making to the operation of physical systems. In this context physical systems are taken to be systems with significant exchange of physical power encompassing the major engineering disciplines. The scope includes vehicles, manufacturing equipment, chemical and other process equipment, power plants, and building services equipment. In conceptual terms mechatronic systems contain four basic elements; the target system, instrumentation, computation and actuation. The mechatronics metaproject is centred on system design. Individual projects focus on real time software, instrumentation, digital signal processing, VLSI design, circuit analysis and multimedia case studies.

Changing the entrenched culture and curricula practices in engineering schools is a major task. Rather than attempting to generate a radically new pattern for engineering education in 5 (or 10) years, the Coalition is attempting to incorporate a Disciplinary or Multi-disciplinary Synthesis Option that forms a common thread or core across the curricula. Rather than providing a series of background courses followed by a capstone design experience as at present, it systematically provides an experience of synthesis in every semester. One example is the Mechatronics option being offered at UC Berkeley:- Year 1 - Interdisciplinary mechatronics design; Year 2 - Artefact dissection; Year 3 - Real-time software; Year 4 - Computer-based instrumentation and measurement.

Given the innate diversity of their academic cultures, sharing ideas between member schools was a fundamental challenge confronting the Coalition. Overcoming the dangers inherent in this was one of the prime objectives of the Coalitions. They have instituted biannual workshops at which individual project leaders meet, display their projects and share their ideas. This has proven to be a very effective means of communication, mutual support, and dissemination of new ideas and methods.

NATIONAL ENGINEERING EDUCATION DELIVERY SYSTEM

A central plank of SYNTHESIS is NEEDS. It consists of three elements: a multi-media courseware development studio at each school to develop learning materials, a distributed database
that enables all schools to access this courseware nationwide and electronic classrooms or other appropriate environments for delivering this courseware. NEEDS supports a distributed database that contains courseware modules composed of some combination of text, graphics, images, and video segments. This material is available to staff and students via the Internet. The aim is to have this material accessible through multiple hardware platforms, from basic PC terminals through to x-windows workstations. The concept is that staff will be able to search the database, review material, select the relevant pieces and combine these into the presentation they are planning. They are assisted in this by NAS (National Access System) a search engine that refers to a centralised library catalogue with a pointer to material at the distributed locations. NEEDS has been evolving in parallel with the rapid developments in the Internet. The appearance of the World Wide Web offers a new form in which to share this material.

Difficulties in the implementation of NEEDS highlight the technological dimensions of diversity amongst the Coalition members in respect of information and computer technology. Initially some schools were heavy users of the Internet while others were not even connected. Some of the schools were exclusively PC sites while others were Mac monopolies. A variety of Unix platforms were in use. These separate histories of technological diffusion are accompanied by cultural norms and expectations about computer technology. These barriers to sharing ideas, let alone resources, are not to be underestimated. A starting point in breaking down this computational tower of Babel, was the agreement that all SYNTHESIS documents would be produced on a Macintosh. In the information age, technical barriers can prove more problematic than geographical ones.

The provision of electronic classrooms and courseware studios also reflects historical levels of resources across the schools. All schools have a base-line courseware studio in a dedicated room. Several schools have fully-functional studios with at least two development platforms. The longer term aim is that all will reach this level and some will achieve mega-studio capabilities with near professional level audio and digital video production equipment. NEEDS is also concerned with incorporating contemporary modes of delivery to students. One example is the $600k state-of-the-art suite of two electronic classrooms at Iowa State. These facilities are yet to be duplicated elsewhere.

Inevitably it is an uneven and evolving technology front that will sweep across the Coalition.

ASSESSING LEARNING OUTCOMES

The Institute for Research in Learning (IRL) in Palo Alto in collaboration with staff from Stanford is evaluating some of the learning outcomes from Synthesis. They are using video records, of students at work undertaking various exercises developed under the Coalition, to evaluate the efficacy of these in fostering student learning, using Video Interaction Analysis (VIA). VIA is a technique for analysing how people in work settings interact with each other and with their work environment, including the documents, technologies and artefacts that they use in their daily work. It is a laborious process that produces rich accounts of what actually happens in work places. It relies on group analysis of video records of activity. The analysis group is cross-disciplinary and might include sociolinguists, industrial anthropologists, educationalists, and designers. The IRL involvement is an extension of its research work on collaborative learning in high schools and at engineering workplaces.

In addition they are investigating the possibility that a form of video analysis might be used on a routine basis for assessing learning outcomes for students engaged in design and other Synthesis where process and the development of procedural knowledge, as opposed to factual knowledge, are crucial outcomes of the educational activity. Their goal is to develop authentic assessment, ways of measuring learning achievements that cannot be assessed by conventional means. This represents a major shift in assessment procedures at the core of engineering education. Assessing individual and team design projects has always been problematic in engineering. Very little work has been published in this field; it is a major omission, and an opportunity, in the scholarship, for underpinning engineering education.

RECURRING THEMES

The NSF Engineering Education Coalitions including SYNTHESIS are prototyping engineering education futures. They are responding to a rising tide of concern about the need for reform in engineering education in North America. Several themes recur: contextualisation of knowledge; diversity (of intake and of outcomes); generalisation rather than specialisation; integration
specialisations and increasingly exotic double-degree combinations. This trend is driven by the desire for market differentiation rather than a consequence of specialisation stemming from the knowledge explosion. Many of the individual projects in the SYNTHESIS Coalition, eg, the use of multi-media, contextualisation, stronger links to practice, have echoes in innovations in Australia engineering schools. Many of the projects supported by CAUT are comparable to work in the Coalitions. The difference is in the degree of common purpose and focus such projects have here, either within Departments or across Faculties or between institutions. The recent CAUT National Workshop on Teaching and Learning in Canberra exemplifies the opportunities that exist for wider and more integrated dissemination and application of teaching innovations across disciplines and institutional boundaries. We need to draw together sometimes disparate initiatives in engineering education across the country around unifying themes if we are to effect the sort of cultural and institutional change that is called for to meet the current and future challenges facing engineering education.

The lessons we learn can be interpreted more broadly. The many questions that are being asked of engineering education around the world lead to two broad types of answer. Many address the question of how we might restructure engineering education, for instance five year courses, increased use of information technology, more effective interaction with industry and introducing more contextual material into subjects. There is an ever present danger however that this focus on the content of educational experiences will not cause the underlying paradigm of engineering education to be questioned and re-cast as appropriate. The more fundamental and challenging questions are what are we trying to accomplish and why. Presented in this form we are confronted by the processes of engineering practice and engineering education. Responding to lists of perceived shortcoming of existing engineering courses focuses attention on the how rather than the more basic, why. The Coalitions are shifting the focus to process. However a warning must be given that the introduction of new technologies to support this fundamental shift in emphasis comes at the risk that the imperatives of these emergent technologies might subsume the primary educational agenda. Implied in the shift from how to why is the necessity for robust scholarly underpinnings,
empirical studies and models, on the cognitive, social and cultural dimensions of teaching and learning. We can no longer afford an arrogant indifference to the vast body of such knowledge available to us. Strategic partnerships like the one between IRL and Stanford are a powerful, cross-disciplinary means of asking the confronting questions: What actually goes on in class? and, What do students really learn and why?

The reductionist paradigm for acquiring and disseminating knowledge of the engineering sciences has served engineering education well for the past forty years. However this has been at the expense of scholarship on the art of engineering, of the development of theories of engineering practice that embody the fullness and subtlety of profession, and that acknowledge it as a social activity played out in a technological context. A new, more inclusive paradigm is needed for the coming decades. The Coalitions offer a foretaste. Through the glass darkly we see the beginnings of a new era emerging in which students learn in an environment where the elegance of the engineering sciences is complemented by an appreciation for the richness of the process and artistry of engineering.

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REFERENCES


BIOGRAPHY

David Radcliffe held academic positions at the Universities of Melbourne and Adelaide before joining the University of Queensland in 1989. Currently he is a senior lecturer in Mechanical Engineering and a Sub-Dean in the Faculty of Engineering. His research and teaching interests focus on the product development process, from design through to manufacture and manufacturing systems. David’s work is underpinned by scholarship that draws on research traditions in education and the social sciences to explore the art of engineering. He is an Associate Editor of the Journal of Engineering Design and the Regional Editor of Design Studies. Over many years he has developed innovative teaching methods and learning environments including the Manufacturing and Design (MaD) Laboratory.

In 1994 David was awarded a CAUT National Teaching Fellowship to study the NSF Coalitions in the USA.
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