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Enhancing Final Year Project Work in Engineering Programmes*

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The explosive growth of engineering complexity and potential that followed WWII exposed weaknesses in theoretical understanding. Universities reacted by replacing practice with theory and practitioners with theoreticians. Pressures from employers and the profession have turned attention to final year projects as the major vehicle to re-incorporate generic skills into the curriculum. The final year project has been construed as a capstone that is placed atop the student's preceding study and is unique in its contribution. The authors argue that this view is intrinsically limited and that, if students are to be sufficiently prepared to reach their full potential, there should be a gradation from analysis to synthesis throughout their educational programme. The authors also comment on the implications of cultural change, student-centred learning, the place of practical skills, requirements of the profession, usefulness to employers and benefits to academics. Examples of practices within the authors' own School at the University of South Australia (UniSA), Adelaide, Australia, are given in order to illustrate the key issues.

INTRODUCTION

The impetus to technological development during and immediately after WWII increased engineering potential exponentially, but also increased the difficulties of conceptualisation and systemic understanding. One reaction to this was to increase the emphasis on, and content of, engineering science and theory in undergraduate engineering programmes.

In programmes of finite length and affordability, that meant something had to go – and that something was practice in implementation and design. Changed priorities brought changes in staffing – theoreticians replaced practitioners – and this, in turn, changed the direction of expenditure on teaching facilities and laboratory equipment (Figure 1). Unfortunately, many graduates were left bereft of practical skills and deprived of initiative – the classic example is the engineer who is unable to change the photocopier cartridge. Protests from industry about the unpreparedness of graduates and a spreading malaise of *paralysis by analysis* (not the authors' phrase, it belongs to a contributor to *IEE News* many years ago) prompted a reversal of this trend in the late 1990s.

Engineering undergraduate programmes have a long lead time and there is a considerable hysteresis effect

Figure 1: The movement from practitioners (left) to theoreticians (right).

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because of staff tenure and the high investment cost of refurbishing and re-equipping laboratories to suit new requirements – particularly given the cost of equipment routinely used for design and manufacture in industry these days. Consequently, change has been gradual and the directions taken have not been uniform throughout the higher education sector. One factor that seems universal is the increasing value being attached to final year projects. Students, academic staff and technicians invest vast amounts of time and energy and expensive resources are monopolised or consumed. Professional societies and accrediting bodies look to the final year project to develop key competences. In one unit of the degree, students are expected to develop skills in problem definition and resolution, design and synthesis, communication skills, commercial awareness, professional attitudes to product and workplace safety ... the list is endless. In this article, the authors reflect on some of the sometimes complementary, sometimes contradictory, views of what is required from project work in design and implementation in undergraduate engineering programmes and how these have been worked through – so far! – in the School of Electrical and Information Engineering (EIE) of the University of South Australia (UniSA), Adelaide, Australia, over the last decade, with particular emphasis on what is happening currently.

THE CAPSTONE APPROACH

Particularly in the USA, the term *capstone* is often used to designate project-oriented courses. Perhaps the vagueness of this descriptor underlies the variability of outcomes from the many courses of this type [1]. After all, a capstone is either a mere adornment to a stone structure or a coping to make it weatherproof – it is unlikely that either of these meanings is what was intended (see Figure 2). However, such definitions of capstone courses as exist do convey an impression of something disparate – although complementary – added on after the main structure is in place. The following is typical:

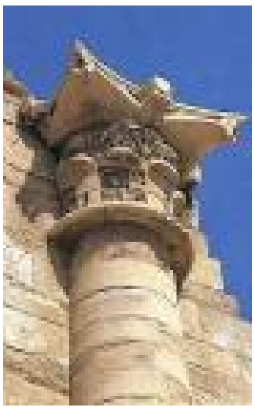
> [Senior-level capstone courses] *provide an experiential learning activity in which the analytical knowledge gained from previous courses is joined with the practice of engineering in a final, hands-on project* [2].

Thus, the *capstone approach* could be seen as adding a culminating component to final year studies, which attempts to blend accumulated theoretical knowledge and engineering practice, usually defined in terms of the Accreditation Board for Engineering and Technology (ABET) 3 criteria (a)-(k) (see Requirements of the Profession discussed below). In this definition, there is no stipulation of the extent to which previous studies are utilised and hence no concept of attempting to integrate and reinforce the corpus of previous study.

One can hardly expect to change the terminology of a decade or more, but *keystone* is a metaphor with a usefully extended meaning. A keystone is scarcely distinguishable from the remaining structure apart from its physical and chronological location, yet it gives strength and unity to the whole of the preceding structure. In fact, it is an object of the designer that it should blend seamlessly with what preceded it. That is a potentially useful way to examine the nature of final-year project work and of the structure of which it should form an integral part (Figure 3).

AN EIE RESPONSE

Up to the early 1990s, engineering programmes at the UniSA were similar to those in other Australian universities in having extremely heavy contact hours in comparison with other disciplines, and a final year with



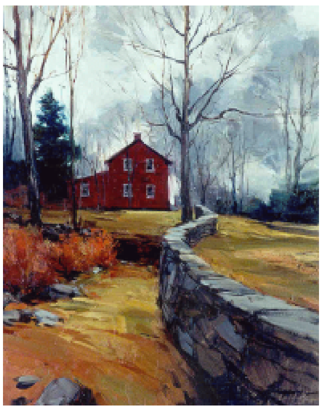


Figure 2: A capstone as an ornament (left) or weatherproof capping (right).

Figure 3: A keystone – not unlike, but integrating, the structure.

major project work, but little allocated time and academic credit. A two-stage process of reform, strongly resisted by many who perceived it as eroding subject specialisms, saw contact hours progressively reduced by 25% and project work extended to between 25% and 50% of the final year student load. An extreme case was the innovation at the Whyalla regional campus where project work and independent investigations occupied 75% of the final year, something aided by the close cooperation that had been forged with local industry [3].

A SHIFT FROM ANALYSIS TO SYNTHESIS

Engineers generally, and particularly engineering academics, tend to be cautious and undertake a good deal of analysing before acting. There are commendable reasons for this where public safety or the economic well-being of enterprises are at risk. Undergraduate engineering degrees and, to an even greater extent, postgraduate programmes are structured along similar lines. It is commonly assumed that acts of synthesis can only follow related theoretical studies. This is not strictly true. Piaget held that, in the developmental sequence of a child, an experimental stage precedes symbolic representation, formal logical operations and abstract thought. The same sequence can be observed with adults confronted with novel situations outside their theoretical framework [4]. This is not to deny that design and implementation is immeasurably enhanced in efficiency, scope and security by appropriate theoretical knowledge.

In the majority of undergraduate programmes, the final year project is the students' first significant engagement with sustained acts of synthesis and practical realisation. Sometimes this requirement leaves students floundering. Sometimes students overreact by abandoning analysis altogether! Pedagogical and practical considerations seem to dictate that experiential learning ought to be introduced much earlier in programmes than is usually the case, even if the outcomes are limited, to impart precursor skills to accompany precursor theory [5]. It is the equivalent of offering students a ladder to help them erect that crowning achievement on top of the often slippery column of prior learning in earlier years (Figure 4).

THE EIE'S ATTEMPTS TO INTEGRATE SYNTHESIS THROUGHOUT THE PROGRAMME

Members of the School realised from the beginning that any move to increase the proportion of final year

Figure 4: Trying to attach the capstone (after Michelangelo).

project work would have to be balanced by earlier work in order to prepare students for the new demands. At first, this need was addressed by an introductory course in the first year (Engineering Systems – ES) introducing generic engineering skills. There were difficulties with this course due to large class sizes and, therefore, large teams with unsuitable group dynamics, and also because of the large time lapse before the final year project.

The next wave of change saw the abandonment of a physical implementation component in the first year course and the introduction of second year courses emphasising the complete design and implementation cycle through a guided step-by-step process (Microprocessor Systems and Implementation – MSI), or for programmes without the same emphasis on digital electronics, a more generic course (Engineering Innovation and Practice – EIP). These were generally more successful [6]. However, the gradual replacement of practitioner academics by theoreticians distorted the implementation aspects of MSI and conservatism marred the elegance and effectiveness of EIP.

Currently, students in the EIE undertake a series of courses that are designed to impart generic engineering skills and a professional approach to the final year project. These are the first year course Engineering Communication and Innovation (ECI), the second year course Systems Engineering Management N (SEM), the third year course Systems Engineering 1 (SE1), and the concurrent fourth year course Systems Engineering 2 (SE2). The effectiveness of the later courses is still being assessed, with the contribution of SE2 being seriously challenged by students.

Within the EIE, a lot of work is being carried out currently to embed achievable and instructive technical project work into the early years of the degree in lieu of conventional laboratory experiments. Thus, first year students are required to progressively assemble a small dc power supply over the duration of their introductory electrical/electronics course. Tests, which would previously have been conducted on dedicated experimental equipment, are now carried out on parts of the power supply as they are added to the circuit board.

CREATING CHOICE

The act of design necessitates making choices between approaches and, once the approach has been determined, between components. As an example of how an elementary laboratory experiment can be transformed into an exercise in design, the following should be considered.

Students will normally be required to test a single transistor amplifier in Class A mode (this mode of operation is common in the low power stages of audio amplifiers). One reasonably flexible method of undertaking this in the laboratory is to use a proprietary Locktronics plug-in circuit board and associated components. The components are mounted underneath compatible proprietary carriers. The standard symbol for the component is engraved on the top of the carrier. By mimicking the circuit diagram, students can construct the circuit using the particular components specified and supplied (Figure 5).

The first step in the modification is to place the physical components on top of the carriers, rather than have a circuit symbol. This introduces a measure of reality. Students will have to consult data books to determine pin-outs on semiconductor devices, and devise their own pattern of layout and interconnection.

Providing students with prescribed components – no more and no less – eliminates the need to choose.

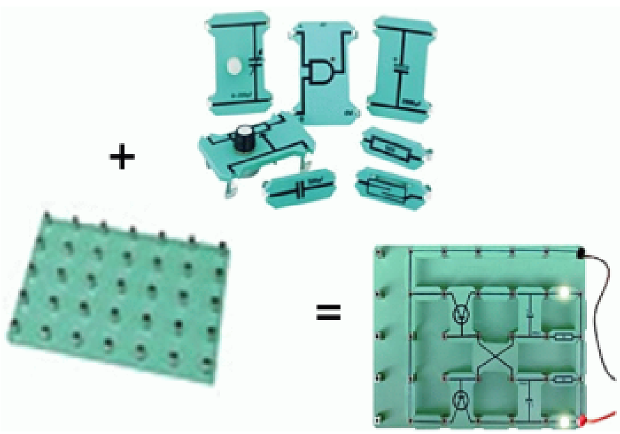


Figure 5: Circuit built using standard Locktronics components.

So it is necessary to provide ranges of components of a similar generic type so that students are compelled to calculate the values and select the components on the basis of published gain, voltage and power ratings, etc.

The next step is to specify the task in an open-ended method that forces students to choose between approaches, eg in the case of the Class A amplifier, to choose a biasing scheme. The choice of the biasing scheme will affect the components needed and their values. So the modified task may look like Figure 6.

THE CULTURAL SHIFT

In the west, it is common for senior high school students to be addressed by their given names and for them to address their teachers by their given names or by diminutives. In the authors' experience this practice is less common in the junior years of universities, but becomes more common in senior years. This might in part be promoted by the notoriously high attrition rates in engineering programmes and the split of the undifferentiated entrant population into disciplinary streams allowing academics to know their students better, but it surely also represents a cultural shift from mere students towards professional colleagues. This effect is strongest in the close contact formed during project work. Even in undergraduate projects, particularly where they involve the solution of industrial problems, it is common for the students involved to transcend the knowledge of their supervisor, so the emerging relationship is both healthy and appropriate. It also enhances the willingness of students to discuss their work on an individual basis, and it can be harnessed to inculcate professional behaviours, attitudes and outcomes. However, similar relationships may be deemed inappropriate in other cultures, or among overseas or international students.

Until he was fired, your predecessor had spent four weeks working on the design of this Class A amplifier.
Complete the design, build a prototype, and test its gain and dynamic range. Are these within predicted tolerances for the components used?

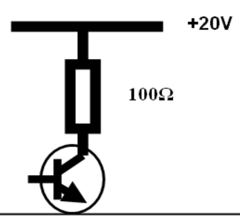


Figure 6: Design-enhanced experiment.

STUDENT-CENTRED LEARNING

Project work is often seen as fostering student-centred learning, which, in turn, may be interpreted as catering for alternative learning styles as a gesture towards adult learning, or as a cost-effective method of delivering education in complex areas with otherwise high equipment demands.

Catering for Alternative Learning Styles

Kolb postulated a cyclical learning sequence in which concrete experience is followed by reflective observation, followed by abstract conceptualisation, followed by active experimentation [7]. Race refutes the cyclical nature of the Kolb sequence, postulating a ripple effect [8]. The present authors have long maintained that learning may occur in any stage of the Kolb sequence and in any order [4][5]. Honey and Mumford have effectively relabelled the Kolb learning activities to create the four quadrants of learning styles [9]. They suggest that, while learners have preferences, a balanced learner will traverse all styles (see Figure 7). Plainly project work both permits and forces this. Consequently, it is not catering for learning styles so much as instilling or reinforcing them.

There is a special consideration applicable to the EIE. Considerable reliance is being placed on the Peer Mentoring Programme to attract school leavers into the School's programmes [10]. This activity is biased towards the Pragmatist-Activist learning quadrants, and so the established preferences of entrants will not match with the Theorist-Reflector orientation of normal academic programmes. This mismatch will make it essential to introduce project work into the junior years of the School's programmes.

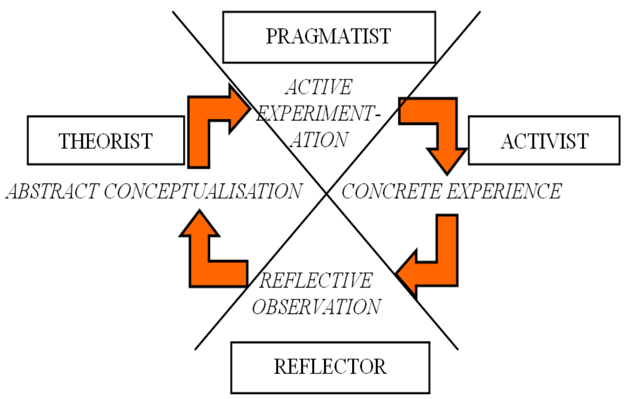


Figure 7: Honey and Mumford's learning styles superimposed on Kolb's Learning Cycle.

Adult Learning

By the time they engage in final year project work, students are physically and mentally young adults. Therefore, it seems appropriate that they should take responsibility for their own learning and determine their own pathways through it. This would seem to argue against a single design morphology, but if there is a conscious attempt to instil a systems engineering approach, then there is merit in imposing structure at reporting points of the design and implementation cycle. The presence within the EIE of a research centre for Systems Engineering (SE) has strongly influenced the curriculum offered to all the School's students and all students are expected to conform to SE principles in their final year project work. This is a genuine instance of drawing on earlier theoretical studies in the final year project.

Cost Effective Education

Making students responsible for their own learning and forcing them to conduct their own literature survey, manage their own prototyping and testing schedule, etc, should notionally free academics from the constraints of classroom preparation. If students have to book the use of scarce equipment and access it at all hours, theoretically this should reduce the need for multiple sets, thereby saving on capital costs. The facts are that student demands on academic time are much greater, and with the possible exception of well-supported industry-based projects, equipment demands are likely to be heavy. This seems to be true whether the project experience is heavily mediated or relatively open-ended.

WHERE DO PRACTICAL SKILLS FIT IN?

Technical staff of the School, motivated by a perfectly reasonable conviction that students should enter their final year projects with a modicum of hand skills, the ability to relate circuit symbols and diagrams to actual hardware, the ability to choose appropriate measuring instruments and interpret their readings, to be familiar with a variety of commonplace implementation techniques and understandings, to possess a sense of time management particularly as it relates to parts procurement and labour requests, and also sufficient sensitivity not to alienate those whose help they need, recently initiated a stimulating debate within the School. There was acceptance that these skills, attitudes and knowledge should be inculcated prior to students attempting their final year project, but differences whether they could be taught in isolation or should be incorporated within experiments designed primarily to reinforce other ideas. That hardy old warhorse, Bloom's Taxonomy, was raked over to determine just what domains (cognitive, affective or psychomotor) were really being addressed in teaching implementation – or should be [11]. At the time of writing, no one has suggested dropping esoteric content to make time for this activity.

REQUIREMENTS OF THE PROFESSION

As intimated, the move towards increased experiential content has been a response to demands by the profession that graduates should acquire and demonstrate generic skills required to bring engineering ideas to fruition. For convenience, the ABET 2000 Criteria 3 are listed below in Table 1 [12]. Other professional bodies responsible for accreditation, such as the Institution of Engineers Australia (IEAust), have similar requirements [13].

Most university engineering departments would believe that students' final year projects provide a *real-life* experience of the practice of engineering and, by choice of pedagogy, enable students to acquire and demonstrate a selection of the generic skills mandated by the profession. However, this cannot be left to chance: each criterion must be specifically addressed and assessed appropriately.

The ABET specifies assessment criteria in Section 4 of its policy document. The dominant paradigm is assessment of outcomes, viz this reflects a product model of accreditation rather than a process one. The same is true for the IEAust, although the movement is towards accrediting on the basis of QA documentation rather than actual demonstrations of achievement.

Table 1: ABET 2000 3 Criteria for Generic Skills Development.

(a)	An ability to apply knowledge of mathematics, science and engineering appropriate to the discipline
(b)	An ability to design and conduct experiments, analyze and interpret data
(c)	An ability to design a system, component or process to meet desired needs
(d)	An ability to function on multidisciplinary teams
(e)	An ability to identify, formulate and solve engineering problems
(f)	An understanding of professional and ethical responsibilities
(g)	An ability to communicate effectively
(h)	The broad education necessary to understand the impact of engineering solutions in the global/ societal context
(i)	A recognition of the need for, and an ability to engage in, life-long learning
(j)	A knowledge of contemporary issues
(k)	An ability to use the techniques, skills and modern engineering tools necessary for engineering practice

COURSE OBJECTIVES WITHIN THE EIE

Learning objectives for final year design and implementation courses within the EIE have fluctuated depending on the amount and nature of preparatory work in earlier years. For example, current students will have been taught the tenets of SE and the form of the associated documentation and are expected to conform to them within their final year projects. Particularly because of the high numbers of industry sponsored projects, there is considerable emphasis on the Requirements Definition phase, a targeted communication activity demanding relevant technical expertise. Other links with the ABET/IEAust criteria are easy to demonstrate. Sometimes, additional exercises in the final year are necessary to further prepare students for all dimensions of the task, eg modules on literature searching and the preparation of research papers.

A typical set of project and supplemental objectives from within the School is as follows:

[On completion of these subjects, students should be able to]

- Consult with a client to establish an engineering specification for a discrete item of equipment or small system;
- Organise resources and time management schedules for a small project;
- Create prototype designs;
- Test and document the prototype;
- Assist in the development of a production version of the design;
- Evaluate the phases of the design/development process;
- Use periodical literature, CD-ROMs, computer-based information services, etc, to research technical topics;
- Prepare balanced and coherent surveys of the literature studied;
- Prepare, present, and defend reports and papers on the topics studied;
- Competently apply the techniques of the topic in the solution of practical problems.

The UniSA has a long history of outcome-based curricula and assessment, and generally the authors find no problem with it. However, it would be unwise to ignore the difficulties intrinsic in specifying and assessing outcomes for a learning process in which students are encouraged to think *outside the box* and assume responsibility for the resulting process. There is a danger that, if outcome assessment is rigidly applied, merit will be unrecognised and plodding adherence rewarded.

> *Let's be honest and admit that things like outcomes-based learning can be a useful approach, but that it* [sic] *can also be a total turn-off. The outcomes achievable by all can be so banal that there is a danger that education becomes a test of who can withstand the tedium longest rather than an opportunity for the exercise of the synapses or a conduit for creativity* [14].

In fact, creeping over-specification of the minutiae of outcomes for final-year design projects within the EIE caused just these problems, requiring rethinking and reform.

USEFULNESS TO EMPLOYERS

For potential employers, the final year engineering project is a litmus test of student interests and aptitudes. At the very least, attendance at symposia of student projects by industry representatives who are informed as to their own labour needs will materially assist them in identifying likely candidates for recruitment. If the industries choose to be proactive, then sponsored student project work may lead to directly useful outcomes and the formation of possible ongoing employment of *their* students.

An aggressive campaign of forging industry links and improving the credibility of the EIE, as well as its staff and students, has resulted in 80% of final year undergraduate projects being industry-sponsored. Figure 8 shows industry and EIE personalities mingling at the annual Industrial Seminar Day.

Students have consistently ranked the *real life* experience of carrying out industry-based projects as the most valuable part of their programme. Anecdotally, the number of students who go on to careers with their industry sponsor is impressive. The achievements of many students already employed by their industry sponsors demonstrate true professional performance and the benefits of access to a full range of current technology.

Figure 8: Industry and EIE personalities mingle at the annual Industrial Seminar Day.

BENEFITS TO ACADEMICS

For academics, final year project work may be one method to stimulate students' interest in research. Capable students are enthused by the act of creation, and encouraged by a mature environment and acclaim for meritorious achievements. Liaison with industry clients and sourcing student projects assists in making individual academics known, and the success of students and supervisors enhances the chances of securing industrial research for reward.

Following a rich academic tradition, academics might view final year projects and student involvement as a way of facilitating their own research, but the time taken to get students up to speed on any meaningful research task usually renders this inefficient. In common with other forms of teaching, final year projects may prove a burden and distraction from other tasks, such as the steadily increasing administrative load and personal research which are obviously more valued in the contemporary university environment.

CONCLUSION

There are many perspectives from which one might view project work within the final year of undergraduate engineering degrees. The intention of the authors in this article is to bring together some of the most influential ones and reflect on their influence on what is generally being asked of this, arguably the most significant part of an engineering undergraduate programme. In particular, the authors have detailed some of the responses of the School of Electrical & Electronic Engineering at the University of South Australia.

The authors hope that this exercise in introspection will serve as a stimulus for further critical review of what we are doing as engineering educators and why. It has already begun to do this for the School's own members.

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BIOGRAPHIES

Kevin McDermott is a graduate of Adelaide University, Kettering University and the University of Southern Queensland. He is a Fellow of the Institution of Electrical Engineers, the Institution of Manufacturing Engineers and the Institution of Engineers, Australia. He worked in the electronics, telecommunications and automotive industries before being allured to academic life in 1973. Among other positions, he was Chair of the Curriculum Committee of the South Australian Institute of Technology from 1988 to 1990. In 1996, he resigned from his position as Head of the Engineering Discipline and Deputy Campus Director of the Whyalla Campus of the University of South Australia.

He is currently a company director, an education and engineering consultant, an arbitrator and mediator, and an Adjunct Associate Professor in the School of Electrical and Information Engineering at the University of South Australia in Adelaide, Australia.

His major research interests are in electrical machines and drives, and the education and formation of professional engineers. Most of his publications are in the area of engineering and university education. Active in professional society affairs, he is an International Membership Advisor of the Institution of Electrical Engineers.

Jan Machotka is an electrical engineering graduate of the Czech Technical University in Prague. He spent more than 10 years working as a professional consultant in industry in Czechoslovakia and abroad. He started his academic career 20 years ago at the South Australian Institute of Technology. He is currently a Programme Director for undergraduate, postgraduate and transnational students at the University of South Australia, Adelaide, Australia. He is also responsible for final year students' projects for four engineering streams in the School of Electrical and Information Engineering. In recognition of his academic efforts, he has received highest University's and national awards. He is also a Chartered Professional Engineer of Engineers Australia.

His major research interests are in computer-aided methods in circuits and systems analysis, e-education, innovations in education, and remote laboratories and experiments. He is a project leader of one of the most successful innovative and learning projects – the remote laboratory *NetLab*, which has gained international recognition.

He has published more than 30 publications, mostly in the field of engineering education.