Can Civil Engineering Students be Taught Design Skills?

Malcolm Jaros[1] and Derek Stretch[1]

[1] Department of Civil Engineering, University of KwaZulu-Natal, South Africa.

jaros@ukzn.ac.za

Abstract

In response to criticism that many engineering graduates are "unemployable", or lacking in marketable skills, the capstone Civil Engineering Design Project at the University of KwaZulu-Natal has been transformed over the past five years. To the original Design Project module, for which students "independently research a relevant Civil Engineering issue and produce a professionally presented portfolio", has been added an introductory Group Phase. In teams of eight the students spend the first month of the final semester of the BScEng programme compiling a feasibility design report for a multi-faceted civil engineering development of current local interest. Engineers who were involved in the design of the development present its principle features and constraints and provide site specific information. These same engineers, or their suitably qualified delegated colleagues, subsequently serve as external examiners of the student's final design portfolios. The objectives are to broaden the conceptual approach to engineering design, address social, ethical and environmental concerns in a sustainable way, and to involve potential future employers of the students in the completion of their academic education.

An internet Learning Management System (Moodle, 2013) is used for discussion forums, file sharing, and anonymous peer evaluation and the students submit, with their portfolio, a spreadsheet that directs the examiners' attention to evidence of their compliance with each of the specific outcomes required by the Engineering Council of South Africa (ECSA, 2004) for professional accreditation purposes.

Feedback from the professional community has been favourable and it is concluded that the transformation has not only improved the quality of graduates as potential engineers but has done so in a structured manner that has eased the work load on the academic staff.

1. Introduction

As African societies grow in size and in lifestyle expectations they need competent Civil Engineers to build new and maintain and improve existing physical infrastructure and environmental conditions.

As a consequence of the inadequate educational opportunities available to their forebears, few South African youths interact with technologically successful role models. The dominant social imperative to improve the life quality of a large proportion of the population absorbs resources that could otherwise be used for advancement of the technologically gifted. Rather than strengthen teaching methods to improve pass rates in secondary education, challenging course content is trimmed and "higher grade" mathematical or scientific subjects are discarded to be replaced by "literacy courses".

Universities tasked with transforming ill-prepared matriculants into engineering graduates are over-reliant on procedural teaching methods that disengage the students from their environment and stifle the self-confident and creative attitude that is the hallmark of a successful professional engineer.

This paper describes how voluntary assistance from experienced design engineers, some retired or employed outside academia, has alleviated staff shortages and encouraged graduates-to-be to engage with the communities that they will serve and the environment that they will be expected to improve.

2. Historical Background

The University of KwaZulu-Natal has, on five campuses and across all disciplines, a total student population of over 40 000 of whom over 9 000 are postgraduates (UKZN, 2013). In the years immediately preceding the creation of UKZN by the merging in 2004 of the University of Natal, Durban (UND) with the University of Durban-Westville (UDW) and other institutions of tertiary education, the two Durban universities offered similar four year BScEng programmes in Civil Engineering, although UDW experienced difficulty in maintaining programme accreditation.

UND had some ten academics teaching classes of between thirty and forty students, UDW about half as many. The class sizes doubled following the merger, and continue to grow, but the combined staff complement dwindled and morale suffered under the perception that academic standards were at risk, if not already compromised.

Research has been strongly promoted at UKZN, diverting the attention of the thinly stretched academic staff from the teaching of undergraduates. This research-centred ethos is expected to improve long term sustainability by attracting and developing new teachers and academic leaders, but until that eventuates it has been necessary, and also beneficial in engineering and related disciplines, to augment the teaching staff by engaging active or retired professional practitioners who are experienced mentors of graduates-in-training but, typically, not qualified educators.

To participate and flourish in a global market of trans-national collaboration and joint ventures it is essential that the quality of local engineers is continuously monitored and upgraded. To this end, the accreditation requirements (ECSA, 2004) of the Engineering Council of South Africa have been realigned to the outcomes and objectives of the Washington accord of 1989, to which ECSA was admitted as a full signatory in 1999. (International Engineering Alliance, 2013).

3. Supply and Demand

The number of pre-qualified applicants for enrolment as Civil Engineering students at UKZN has consistently exceeded the annual limit of 100 acceptances that is constrained by the size of available lecture venues and the limited number of teaching staff. All completing students are believed to have found permanent employment in South Africa within three months of graduating, unless they were either foreign nationals without work permits or had opted to continue with postgraduate education. Criticism by employer bodies of the quality of tertiary education has become muted in relation to more strident complaints regarding the quality of primary and secondary schooling. While imperfections in the South African education system as a whole are being addressed at national government level the education of civil engineers has relied upon support from utility providers, local-government bodies and commercial organisations either directly through endowments and salary subventions or indirectly through organisations such as the South African Institution of Civil Engineers (SAICE), the South African Federation of Civil Engineering Contractors (SAFCEC) and Consulting Engineers South Africa (CESA).

For UKZN Civil Engineering this support is a reflection of sustained engagement over several decades by academic leaders with alumni and the engineering community, invigorated in 2008 by the SAICE report on "*Numbers and Needs*" (Lawless, A. 2008) compiled and promoted by Allyson Lawless FRAE, who graduated from UND in 1973 and became national president of SAICE in 2000. The report starkly details the critical local shortage of adequately trained engineers and technologists and provides clear evidence of the dependence of sustainable economic and social development in South Africa on the number, quality and demographic distribution of trained civil engineering professionals.

4. ECSA Accreditation of the Civil Engineering BScEng Programme at UKZN

All tertiary education programmes in South Africa that lead to the award of degrees or diplomas requisite to registration as Professional Engineer, Pr Eng, or Professional Engineering Technologist, Pr Tech Eng, are audited quinquennially by ECSA. At UKZN the Civil Engineering BScEng programme was audited in 2008 and the 2013 audit is currently in progress. The audit evaluates a wide range of qualities (ECSA, 2004) that engineering programmes must exhibit in order to meet the standards required for accreditation, including enrolment criteria, course content, laboratory equipment, computing and teaching facilities, administration, documentation, staffing levels and qualifications, assessment criteria and exam pass rates. Of special interest here are the ten mandatory competencies expressed as Exit Level Outcomes that must be demonstrably attained by every graduate from the programme. The Outcomes may be briefly paraphrased as the ability to competently:

1. Identify, assess, formulate and solve concrete and abstract engineering problems that require judgement to deal with uncertainty.
2. Apply, from basic principles, mathematical and scientific knowledge to the solution of open-ended engineering problems.
3. Creatively plan and execute the engineering design process to recognise and meet user needs within applicable social, legal, health, safety and environmental constraints.
4. Design and conduct investigations and experiments, after critical review of existing related knowledge, to advance understanding of a phenomenon and recommend a course of action.
5. Select and use appropriate engineering methods, skills and tools, including numerical modelling, and to critically evaluate the accuracy, meaning and relevance of the end results.
6. Communicate effectively both in writing and orally, with engineering audiences and the community at large, using appropriate language, drawing and audio-visual skills
7. Demonstrate critical awareness of the impact of engineering activity on the social, industrial and physical environment i.e to incorporate sustainability into the design process.
8. Work effectively as an individual, in teams and in multidisciplinary environments, accepting support from and assisting group members while making a specific individual contribution.
9. Engage in independent learning through well-developed learning skills by sourcing, critically evaluating and organising information with initiative in complex or ill-defined contexts
10. Act professionally and ethically in the exercise of judgement, identifying and accepting responsibility for working within personal boundaries of competence

Evidence of compliance with each of the ten Outcomes is required from every student, either in the Design Project or the concurrent Research Dissertation to which the final semester is devoted, although most of the Outcomes would have been addressed to varying degrees in previous years and evidenced in the assignments and externally moderated examinations of the three 16-credit “major” modules of the penultimate semester and the two final year 8-credit modules. (See Table 1.)

The 2008 audit was successful to the extent that Civil Engineering at UKZN was found to have actively engaged the 2004 version of the E-02-PE: Standards (ECSA, 2004) and was the first BScEng programme (together with the associated programme of Agricultural Engineering) to achieve an unconditional five year accreditation in terms of these Standards. However, acclaim was not unanimous. The exit report of the auditing team highlighted weaknesses that needed attention and the reaction of the academic staff, and especially of their assisting professional practitioners, to the emphasis on assessing compliance with the ten Outcomes was not encouraging. The wording and format, if not the intent, of the Outcomes were unfamiliar and there was a suspicion that their purpose was to mask a lowering of standards that would be exacerbated by loading the staff with unnecessary additional administrative tasks. Resentment was fuelled by the requirement, lacking a common set of criteria, to make both an “outcomes based” and a “quality mark” assessment of each student. This conundrum was resolved (Stretch, 2007) by compiling an assessment questionnaire for the Design Project (and another for the Dissertation) in which the questions were worded in the terminology of the Outcome definitions but the responses were weighted and aggregated in a spreadsheet that mimicked the “quality mark” assessments of the traditional system. Experience in usage and improvements in the functionality of the spreadsheets have since persuaded the examiners that the new system is a rational and efficient substitute for the old and has improved uniformity of assessment standards across portfolios that vary in subject matter and complexity.

Table1 : Outcomes Addressed in Externally Moderated Exit-level Modules.

MODULE DESCRIPTOR	**Credit wt.**	**MODULE MARK DISTRIBUTION**		**ECSA Outcomes***
Semester 1		**Not moderated**	**Moderated**	
Ground & Structural Engineering	16	Groupwork 20% Tests 20%	Final Exam 60%	1, 2 & 3
Water & Environmental Engineering	16	Test & assignments 40%	Final Exam 60%	1, 2 & 3
Transport & Environ. Management	16	Test & assignments 40%	Final Exam 60%	1, 2 & 3
Professional Practice	8	Test & assignments 40%	Final Exam 60%	8 & 10
Semester 2				
Management of Constr. Contracts	8	Test & assignments 40%	Final Exam 60%	7 & 10
Design Project	24		Groupwork 25% Individual 75%	All except 4 & 9
Dissertation	24		100%	All except 3
*** Outcomes that are addressed in each module but summatively assessed only in the Design Project and Dissertation**				

5. The Civil Engineering Design Project

The two 24-credit capstone modules of the final semester have always been regarded as show-pieces of the ability of the students, as individuals with minimal supervision, to conduct scientific research (Dissertation) and engineering design (Design Project). Students were traditionally allowed, under the guidance of a nominated Supervisor, to select and develop their own topics and, broadly speaking, each topic was unique. That is largely still true for the Dissertation, but the transition to the Outcomes based assessment system and specifically the need, in terms of Outcome 8, to demonstrate the ability “to work effectively … in teams and in multidisciplinary environments” motivated the addition of the preliminary Group phase to the individual Design Project.

The Design Project is themed each year on a multi-faceted development of current public interest. The development may be in the planning stage, out to tender, under construction or fully commissioned. Key requirements are that the purpose and characteristic features of the development have been widely publicised, that an extensive database of design features and constraints (geotechnical, environmental and survey reports) are accessible (preferably in the public domain) to the students and that significant elements (Topics) of the development have been designed by locally based engineers who are willing and qualified to familiarise the students with their design Topic, arrange site inspections, seminars and Q & A sessions where appropriate and, ultimately, to act as External Examiners. Recent projects were:

2010 - Greenfield development of a resort village incorporating a river estuary.

2011 - New town centre with a commuter rail terminal beneath a multistorey shopping centre, bus and taxi-ranks, adjacent to a hospital and a wetland.

2012 - Dig-out harbour with facilities to trans-ship 12 million containers per annum.

For each project four structural (reinforced concrete, steel-framed, post-tensioned concrete and geotechnical) and four civil engineering (transport, hydrodynamic, reticulation and waste treatment) design Topics were identified. The class was divided into Groups of eight and each Group had four weeks to assess the data provided, identify and source further information and compile a Feasibility Report that described the essential features and constraints of the development. Crucially, the report had to include detailed design briefs for the eight Topics that had been distributed by negotiation between the Group members.

Three days after the printed reports were delivered to the Examiners, each Group made an audio-visual presentation of their report after which they were awarded a common Group Mark constituting 20% of the aggregated course mark and individually a differentiated potential 5% of which half was determined by anonymous peer assessment by the members themselves and half by the Examiners' perceptions of the contribution made by each member to the Group effort. The Groups disbanded immediately following this assessment and the members proceeded to complete their Individual Design Topics in the traditional fashion.

6. Advantages Accruing from the Group Phase

Improved Productivity

Introduced essentially to meet Outcome 8 there was an initial perception that the Group Phase was time wasted and that students who found it difficult to simultaneously complete their design Project and research Dissertation in a total of fourteen weeks would be further stressed. Instead, the Group phase has been found to accelerate progress on the Projects and to significantly improve the quality of the designs produced. In the past some student were still struggling, several weeks into the semester, to formulate a meaningful design brief. This problem has been largely eliminated by the peer pressure and support generated by the need for the Group to make their formal presentation within four weeks.

It has been found possible, for these initial four weeks, for the module Coordinator to act as Supervisor to the entire class, given the freedom to call for support as required from colleagues or external mentors.

Broader Attention to Sustainable Development

Two of the three exit level “major” modules include environmental engineering and environmental management but few of the design project Topics maintain this focus on engineering for sustainable development. While it would normally be inherent in the design of a waste-water treatment facility, and Green Star ratings attract much attention in the design of habitable structures, sustainability is seldom a prominent element in the design, for example, of a railway bridge. Environmental legislature is complex and, at the design and planning stage, sustainability requirements need to be considered on a multi-disciplinary basis that is of too broad a scope to be dealt with, in the time-scale of the Design Project, by individual students. The Group phase encourages the consideration of sustainable development at a higher level and on a broader base than is warranted in the Individual phase.

Enhanced Student Engagement

Students who are reluctant to communicate their difficulties to a formal Supervisor can often find solutions through discussion with their peers who, if they cannot help directly, can provide encouragement to pursue the query through other channels. The Supervisor normally responds only to emails received via a “forum” that delivers the message simultaneously to the student's particular Group or, if of a more general interest, to the entire class. The enforced team interaction helps most students, especially the introverted, to explore new ways to find solutions and reduces the time-demand on the Supervisor who can more usefully respond to less frequent and better formulated appeals for guidance.

This benefit alone justifies the time invested in the Group phase.

Value Added by the Anonymous Peer Assessment

The students are required to each submit an Anonymous Peer Assessment of the members of their Group through the Questionnaire facility (Questionnaire, 2013) on the Learning Management System (Moodle, 2013). Although they only use it four weeks later, the procedure is demonstrated in the first week together with other features of the LMS such as posting to a forum, sending a personal message or simply accessing various parts of the common database. All of the students have had some experience with the LMS in pre-requisite modules and have even, in the previous semester, participated in a similar APA designed to address concerns regarding “invasion of privacy”.

The APA Questionnaire requires the respondent to “*rank the members of your Group, including yourself, from highest to lowest*” in each of seven categories that can be captioned respectively as Innovator, Researcher, Calculator, Illustrator, Draughtsman, Editor and Motivator. The “radio-button” format of the Questionnaire does not allow two persons to receive the same rank in the same category. For any one category this is unfair where several members have contributed equally, but across the seven categories it is not difficult to adjust responses to compensate for such injustices or even to ensure that all members in the Group receive the same overall ranking.

That the APA contributes only 2½% to the aggregate grading does not detract from its purpose of promoting team effort. The key element is that the students are made aware, before they start the Project, of the criteria that will be used to assess their performance as team members. This may help the Group achieve a better overall grade-mark but it also counters the tendency of weaker students, in a groupwork situation, to sit back and wait for others to carry the load.

7. Assessment of the Individual Phase of the Design Project

Self Assessment by the Students

With the completed Design Portfolio, each student includes a self-assessment in the form of a five-page spreadsheet workbook on which the criteria relating to each of the eight Outcomes is briefly paraphrased. For each Outcome the student identifies the section of the portfolio where evidence of compliance can be found (Figure 1). The Examiners' task is to check the evidence and enter into the spreadsheet a quantitative assessment of the extent to which each Outcome has been met. The assessments are automatically aggregated (Figure 2) and reported on a covering summary sheet. If all eight Outcomes have clearly been adequately addressed then the student is awarded a final mark that includes those marks previously awarded in the Group phase. If at least one Outcome has clearly not been met then the student has failed the module. If it is uncertain whether one or, marginally, two Outcomes have been met then the student is granted a seven day “upgrade period” in which to provide additional supporting evidence of compliance.

ECSA OUTCOME 2: Application of Scientific & Engineering Knowledge	Y_1	Y_2	Y_3	?	N
Assessment criteria : Has the candidate demonstrated the ability to use basic		Weight	15%	Mark	10.5
science and maths to solve engineering problems and design components/systems/processes by …					
2.1 rationalising concepts and ideas using physical laws, mathematics or statistics?					0.7
2.2 using engineering techniques and principles to model open-ended problems?					0.7
2.3 applying engineering and mathematical methods of analysis and modelling?					0.7
2.4 using mathematical, numerical or statistical methods to deal with uncertainty & risk?					0.7

Documentary Evidence in Portfolio :- *(candidate to complete, with specific reference to each assessment criterion)*

2.1. The concept and methods in the design of spillway, water balance, pipe sizing and flood routing. See calc sheets 29-40.
2.2. Open ended problem of uncertain water supply to the lakes was dealt with by modelling the water balance See section 3.3.3. of report and also digital copy (on CD) of spreadsheet used for modelling the water balance.
2.3. Mathematical analysis and modelling were used in the flood routing (forward difference numerical model) and in the direct step method used to analyse the spillway
2.4. Uncertainty and risk is dealt with in the flood estimation (sections 3.3.1. and 3.3.2). Uncertainty in the results of the method was dealt with by cross checking with alternative methods

Figure 1: *Details provided by student of evidence of compliance with Outcome 2*

INSTRUCTIONS TO EXAMINERS

1. Examiners assess achievement of outcomes on the basis of evidence cited by the student.
2. The oral examination may be used to gather further evidence if required.
3. The same evidence may be used to show achievement of more than one outcome.
4. The results are reflected as “YES”, “NO” or “?” (questionable) using a 5-point grading :-
   “YES” = Y1 (high level of competence), Y2 (average) or Y3 (acceptable)
   “?” = additional evidence to be provided within one week (upgrade required)
   “NO” = outcome not achieved and is not upgradeable.
5. Examiners should explain deficiencies where outcomes are not adequately demonstrated.

ENDORSEMENTS BY EXAMINERS & MODERATOR

I CERTIFY THAT THIS STUDENT'S DESIGN PROJECT SUBMISSION HAS BEEN ASSESSED USING THE CRITERIA SPECIFIED IN THIS DOCUMENT.

	Yes	?	No	Indiv. mark	Final Mark	Result
ECSA outcomes met :-	6	1	1	33%	**	FAIL

Figure 2: *Explanation and summary of aggregated Outcome and ”quality” mark*

Advantage of having Eight Design Topics

When the students had a wide choice of Design Topics it was difficult to find, for each individual student, a Supervisor, an Internal and an External Examiner. A complex task for a class of forty students became unmanageable with a class size of eighty. Within the limited pool of qualified External Examiners, few were willing to assess more than two design portfolios and, with dozens of Examiners assessing unrelated designs, the quality of the marking was erratic. The single standardised Outcomes-based assessment procedure, embedded into the self-assessment workbook, made it possible to grade-mark ten portfolios in a total of 24 hours, including eight hours of oral examination. Under these conditions it became a simple matter to find eight External Examiners and eight Supervisors, each willing to deal in a structured fashion with ten students executing similar design briefs over a period of seven weeks, reduced from the original eleven weeks by the separately supervised and assessed four-week Group phase.

It also became feasible for the module Facilitator to over-view all eight of the eight-hour oral examination sessions, at which the Internal and External examiners jointly agreed assessments, to effectively normalise the quality of marking across the eight Topics.

8. Conclusions

The BSc capstone Civil Engineering Design Project module at UKZN has been modified, primarily to include an initial Group phase but also to produce, for each student, detailed evidence of compliance with eight targeted ECSA Outcomes. These changes have further served to:

- improve the students' understanding of what they should deliver and how that will be assessed
- relate the Design Project to current, high profile, local developments "in the real world"
- bring sustainable development to the forefront of the design process (Outcomes 3 & 7)
- develop and assess each student's ability to function as an effective team member (Outcome 8)
- build peer assessment into the grading process and encourage student interaction
- facilitate participation of experienced practising and retired professional design engineers
- engage employer bodies in the final phase of the education of potential employees
- handle greatly increased student numbers with a reduced staff complement

9. References

ECSA, 2004. *E-02-PE: Standards for Accredited BSc(Eng)/Beng Programmes. Engineering Council Of South Africa*, http://www.ecsa.co.za/documents/040726_E-02-PE_Whole_Qualification_Standard.pdf

International Engineering Alliance, 2013. http://www.washingtonaccord.org/Washington-Accord/signatories.cfm

Lawless, A. 2008. *Numbers & Needs in local government*. South African Institution of Civil Engineers. ISBN Number: 978-0-620-39928-9

Moodle, 2013 https://moodle.org

Questionnaire, 2013 http://docs.moodle.org/24/en/Questionnaire_module

Stretch, D.E. 2007. *Assessment Process for ECSA Exit Level Outcomes.* CESC – AO/1/2007

UKZN, 2013 http://www.ukzn.ac.za