Paper 32. Embedding sustainability into the Civil Engineering Curriculum – a design based approach

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Abstract

In 2007-08, the School of Civil Engineering and Geoscience at Newcastle University (NU), UK conducted a root-and-branch review of its undergraduate (UG) Civil Engineering (CE) provision. It produced a vision for a Programme that 'engages students with the global challenge of engineering a sustainable future for the planet, placing Civil Engineering at the heart of delivering infrastructure and living environments that are sustainable in the 21st century and beyond'. To meet this challenge, the CE UG Programme needed to evolve from its traditional narrow remit of design, which devises a chosen solution from amongst several purely technical options, to a much broader whole-system approach to design that accounts for the increasingly complex interdependencies and interactions between the built environment, the natural systems and cycles that sustain life on Earth and the pressures and demands that human populations and networks place on these systems.

After an extensive and iterative process of consultation and development, the CE UG Programmes which emerged had systems-based integrated design modules running as a continuous and unifying theme throughout its first 4 years. It challenges our students to think not only about the technically demanding subjects but also about the future challenges of climate change, sustainable development, democracy, equity, poverty alleviation, and the lifelines of energy, food and water. Through this approach we have achieved a much higher level of interdisciplinary integration of knowledge, and much greater consideration of sustainability and systems-level thinking in the delivery of our programmes. The aim of these modules, collectively named "Design of Sustainable Engineering Systems (DSES)" is to integrate the knowledge and skills gained in the Programme into a sustainable engineering design approach that is fit for the 21st Century. Arup have been our partners in the development of this integrated design theme, ensuring that current and leading edge engineering practice in the area of sustainability is embedded into the design and delivery of the modules. This has been achieved through two, parallel funded projects by the Royal Academy of Engineering in which Andy Mace, a leading practitioner in sustainable engineering design from Arup joined the School as a Visiting Teaching Fellow in Engineering Design and Stephanie Glendinning joined the Arup Consulting team for a 12 month period.

Five years on from this review, we now have a programme which is an exemplar of sustainability embedded into the Civil Engineering curriculum and of University-industry collaboration. This paper will summarise the process of curriculum development, the balance of the sustainability strand and the trade-offs which had to be made with more traditional material. The paper will also describe the evaluation of the content and the effectiveness in skills development in the students and the feedback from internal and external stakeholders.

1 Introduction

The School of Civil Engineering and Geosciences (CEG) at Newcastle University (NU), UK, is one of the leading institutions for Research in Civil Engineering in the UK (rated 2nd for research "power" in the most recent national review of UK research in Civil Engineering). This was founded on exemplary practice in interdisciplinary research, with the core of the research driven by the ethos of 'Earth Systems Engineering', the engineering of coupled human, ecological and infrastructure systems under global change. This was contrasted with an Undergraduate Programme which was failing to engage the best research-oriented academic staff in its delivery, resulting in a 'could do much better' result from a review in 2007 by the Joint Board of Moderators (JBM), the body which represents both academic and industrial views of the relevant Professional Institutions.

One of the positive aspects of the Programme was our interdisciplinary approach to design-based teaching, which was highlighted by our External Examiners as a core strength of the Programme. We aimed to build on this strength to provide the platform for engaging the students with the global challenges of sustainability and sustainable development, and for motivating the best research staff in developing and delivering a new and exciting Programme. This sort of change could not be retrofitted onto the existing Programme, or boxed into a single module, and so a vision was developed by a series of consultation exercises with staff, students and industrial advisers. It was based around developing a Programme which placed Civil Engineering at the heart of delivering sustainable infrastructure and living environments in the 21st century and beyond. It needed to capture the best of our research in a way that could be relevant and motivating for students. This strategy was endorsed by Parkin (2008) who identified the failure of undergraduate engineering programmes to motivate students in the challenges of sustainability, and to integrate sustainability properly into the curriculum.

This paper will describe the process of curriculum development and delivery and the feedback received from internal and external stakeholders.

2 The process of curriculum development

A strategic review of the UG CE programmes was initiated in the spring of 2007. This took the form of an extensive consultation with the various CEG groups. In early 2008, a document entitled 'The Future of Civil Engineering Degrees', which summarized the outcome of this exercise was circulated to all staff for further consultation. It took the form of a SWOT analysis of a set of possible options which might be pursued in evolving the UG programmes. The preferred option to emerge from the SWOT analysis consultation was 'Integrated Systems-based Programmes'. In February 2008, a Strategy Working Group was established to consider how the current Programmes might be evolved, consisting of a number of Professors who represented all of the disciplines in CEG. The idea was to engage the best research Professors in the very core of the Programme and thereby 'lock them in' to its design and delivery.

In order to achieve our ambitions we needed to evolve a Programme consisting of a set of modules which each took a traditional narrow disciplinary approach to design, in which a chosen solution is selected from amongst several purely technical options, to an integrated Programme which took a much broader whole systems approach to design. We wanted students to develop the ability to account for the increasingly complex interdependencies and interactions between the built environment, the natural systems and cycles that sustain life on Earth, and the pressures and demands that human populations and networks place on these systems.

This could not be achieved by designing a Programme around a collection of modules managed via the traditional disciplines of Civil Engineering and using these to develop knowledge and skills. We applied our-whole-systems approach to the design of the Programme and what emerged was a systems-based integrated Programme with a dominant inter-disciplinary design-based core. This core had sustainable development at its heart, engaging with the environmental, social and economic dimensions of this unifying concept in the design and, implementation, and rehabilitation of all Civil Engineering interventions within the Earth system. It was designed to challenge our students to think not only about the technically demanding subjects but also about the future challenges of climate change, sustainable development, democracy, equity, poverty alleviation, and the lifelines of energy, food and water.

Through this whole-systems Programme approach, we achieved a much higher level of interdisciplinary integration of knowledge, and much greater consideration of sustainability and systems-level thinking in the delivery of our Programme. The 5 themes which now comprise the CE UG Programme are illustrated in Figure 1.

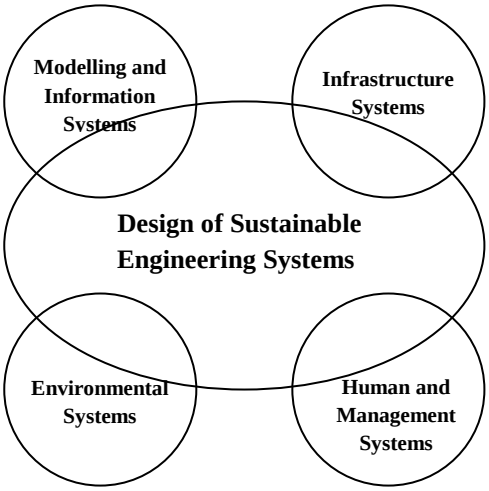


Figure 1: Thematic structure of CE UG Programme

Of particular note is that the themes are not rooted in the traditional disciplines of Geotechnics, Structures, Hydraulics etc, although of course, they are still embedded in the content. Moreover, we eliminated the frequent duplication of the teaching of numerical modelling and information processing across disciplines by having an overall theme of 'Modelling and Information Systems'. Furthermore, there is a 'Human and Management Systems' theme which recognises that civil engineering is about designing for peoples' needs and wants, is intrinsically linked to societal structures, but at the same time engineered systems sometimes have detrimental impacts on those people which they serve. The centre-piece of the Programme is the 'Design of Sustainable Engineering Systems (DSES)' theme which takes a whole-systems approach to design, with a focus on projects that allow the integration of knowledge across all the disciplines into a sustainable engineering approach.

Each theme was managed by a discipline-based Professor who took charge of the development of the knowledge and skills development throughout the stages of the Programme (Years 1-4). Each existing module was mapped onto the new structure and decisions made about the requirement for replacement module content and/or replacement modules. The theme leaders convened consultation groups consisting of all the module leaders within the theme in order to undertake this process collaboratively.

Inevitably, this led to trade-offs being made between traditional, often more technical, material and the softer, more broadening, subjects that constituted the sustainability dimension. Careful attention was paid to keeping *essential* material through a process of iteration, internal and external consultation and comparisons with other Programmes from other leading UK institutions. Table 1 shows the module titles which were present in the old Programme and those now present in the new Programme As can be seen, the core material of the civil engineering discipline is still present in the new Programme. An additional emphasis on the human dimension of civil engineering practice and sustainability is expressly listed as modules in all stages. This can be used to highlight the importance of these considerations to the students in preparation in becoming a professional engineer.

A detailed specification for the Programme emerged in late 2008, which was discussed in detail with the then External Examiner and the Chair of the 2007 JBM Review who provided detailed (and highly encouraging) feedback on Programme content.

Furthermore, each year, or Stage, in the Programme was assigned a Stage Leader who was responsible for the development and management of the balance of transferable skills across each stage. Module leaders were requested to integrate the coursework for their modules within the framework of the Core DSES module, thus simplifying the design of skills development and coursework scheduling. The aim was to integrate the learning, development and practice of transferable skills (analysis, design, advocacy, presentation, drawing etc.), resulting in a portfolio of design work from concept through to delivery for all four years

The design of this central DSES core was critical to the success of the Programme and an 'Awayday' was held for all staff as part of its development. This Awayday defined the objectives of the DSES theme, which are developed through the first three years of the Civil Engineering Programmes, as follows:

Stage 1: Introduce and define sustainability and the context of global change. Review the requirements for a small-scale sustainable development. Develop awareness of inter-linkages of systems, and develop ability to carry out conceptual design.

Stage 2: Develop more specific analysis and design skills in a larger case study. Further understanding of the sustainability agenda, together with life-cycle analysis and risk management.

Stage 3: Develop specific designs for sustainable solutions to complex systems. Present and promote designs in a multi-disciplinary team-working context. Understand and practice methods of climate change adaptation and mitigation.

In **Stage 4**, DSES is delivered as an individual investigative project, often related to the research of individual members of research staff, and invariably having a sustainability dimension.

From this, detailed Module Outlines were produced which progressed through the University systems of approval, and the new Programme was 'rolled out' year-on-year starting with Stage 1 in 2009/10. The first complete new Programme across all Stages/Years was delivered in 2011/12.

Table 1: Summary of module changes which occurred within the Civil Engineering curriculum in which all the essential CE core material is still present.

Stage	Old Programme	New Programme	Key information
1	Integrated Design	Design of Sustainable Engineering 1	Core fundamental concepts of civil engineering introduced. Holistic design approach adopted.
	Sustainable Solutions in Civil Engineering		
	CAD concepts	Engineering Communication and Visualisation	
	Water and Environmental Systems	Environmental Systems	
	Introduction to Geotechnical Engineering	Geotechnical properties of soils and rocks	
	Engineering properties of Materials	Engineering Mechanics and Materials	
	Introduction to theory of Structures		
	Fluid Mechanics	Fluid Mechanics	
	Engineering Mathematics 1	Engineering Mathematics 1	
	Engineering Surveying	Engineering Surveying	
	Transport Management and Policy	Human System Demands and Impacts	
2	Integrated Design 2	Design of Sustainable Engineering Systems 2 (DSES2)	Large design project incorporating industry based lectures on construction health and safety practice. Lectures delivered on materials during DSES2 module relating to design project. System components of the core civil engineering disciplines are covered in this year
	Construction Materials		
	Construction Practice		
	Programming for Engineers and Scientists	Engineering Informatics	
	Water and Waste Management	Treatment of Water and Wastewater	

	Introduction to Geotechnical Design	Geotechnics	
	Theory of Structures	Structural Analysis	
	Transport Engineering	Land use and transport planning	
	Statistical and Numerical Methods for Civil Engineers	Statistical and Numerical Methods for Civil Engineers	
	Steel and Concrete Structures	Steel and Concrete Structures	
	Engineering Surveying	Engineering Surveying	
3	Multidisciplinary design project	Design of Sustainable Engineering Systems 3	Large design project focused year with the theoretical modules feeding into the design project. 2 phases of design over the year (DSES3 and SEDP), a large conceptual masterplan developed in small groups (DSES3) with detailed design of the masterplan achieved in SEDP of the year. These detailed design teams are subdivided into discipline-orientated design groups with group management and communication key to delivery of a successful project. Key modules in Ethics and Sustainability and in Construction management encourage holistic systems design to take place. *Optional modules available requirement to do 2 of these. New programme has NO options available
	Advanced Structural Materials		
	Elements of Economics and Business Finance		
	Civil Engineering Practice	Sustainable Engineering Design Project	
	Matrix Methods of Structural Analysis	Computational Engineering Analysis	
	River and Coastal Engineering	Hydrosystems Engineering	
	Engineering Ethics and Sustainability	Engineering Ethics and Sustainability	
	Geotechnical Design	Geotechnical Design	
	Design of a transport infrastructure*	Structural Analysis 2	
	Geotechnical Engineering*	Design of Building Systems	
	Water and Wastewater treatment processes*	Construction Management	
	Sustainability and water resources*	Design of transport infrastructure	

3 Industrial Collaboration

It was considered essential that the new Programme should have current practice, particularly in the area of sustainability, embedded within it. Arup were identified as leaders in sustainable engineering, with a local office in Newcastle with whom we could interact effectively. A dialogue was opened up between the University and Arup from which two, parallel two-way secondments were undertaken with the support of the Royal Academy of Engineering (RAEng). Andy Mace, a leading practitioner in sustainable engineering from Arup was appointed as an RAEng Visiting Teaching Fellows in Engineering Design to help design and deliver the DSES modules in a way that would ensure that Graduates had the skills industry needed; Stephanie Glendinning, an academic in CEG, joined Arup in order to gain first-hand experience, project knowledge and data to bring back into the delivery of, in particular, DSES.

Furthermore, this collaboration has developed over the years of designing and implementing the Programme into a lasting relationship between Arup and CEG which is being sustained beyond the lifetime of the secondments. This has resulted in the involvement of a wider pool of Arup staff in the delivery and assessment of the Programmes. Furthermore, we have signed a Memorandum of Understanding between NU and Arup which supports collaborative research activity with a wider group of staff. This legacy will ultimately ensure that the Programme is continuously updated with current industrial practice and that our research will feed its way back into the Programme.

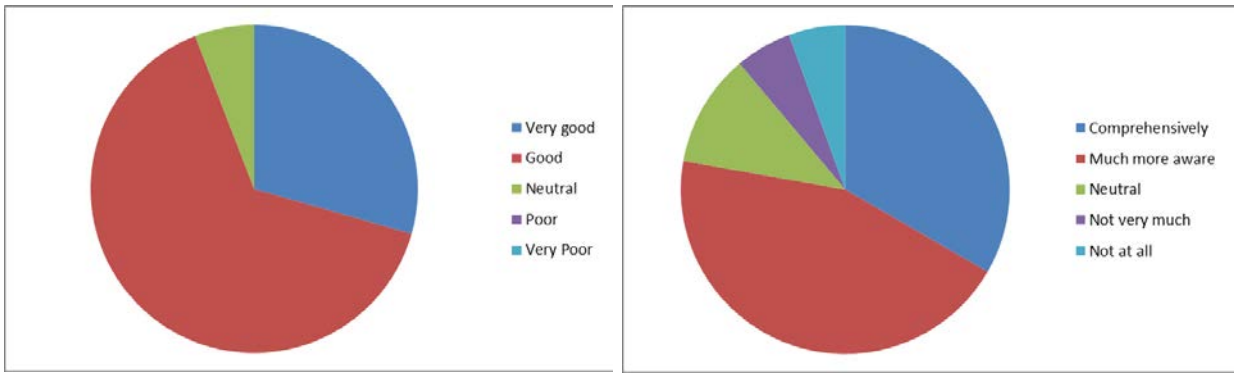
4 Evaluation

It was appreciate that we needed to undertake another consultation exercise at the end of the process to evaluate whether we had achieved our aims from a stakeholder perspective. This evaluation took the form of questionnaire surveys and discussion groups with both students and employers. A summary is presented here.

4.1 Student Evaluation

Students were surveyed using questionnaires about the DSES theme as a whole. Feedback from this exercise indicated that overall over90% thought that the modules were interesting and relevant, with positive comments written about the Arup contributions in particular. Furthermore, the commentary provided in the feedback from the students was particularly enlightening about their attitudes toward the theme as a whole. A Stage 1 DSES student remarked that ‘What I like about this module is how all the modules integrate in one module giving the sense for students to feel like a real engineer’. This is particularly encouraging as it was one of the particular aims of the DSES theme.

Stage 3 feedback, illustrated in Figure 2 demonstrates that the students found the module interesting and felt that their sustainability knowledge had improved. Feedback comments include that ‘the sustainability framework concepts were useful’ and that there is an ‘appreciation of the complex and conflicting issues’ surrounding the delivery of sustainable development. This is a demonstration of fulfilling a DSES theme aim of integrating systems and sustainability concepts in the design process.



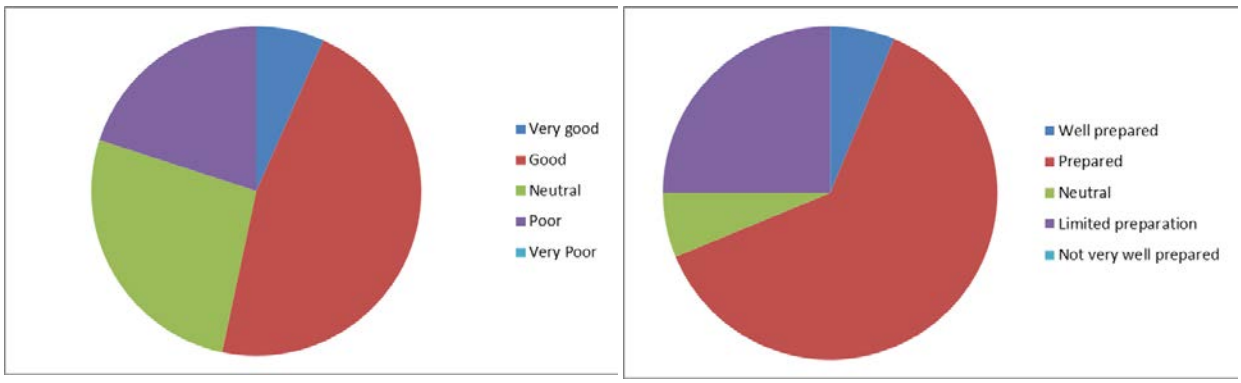
(a) Did you find that this module was interesting?

(b) Has the module improved your understanding of sustainability concepts in the construction industry?

Figure 2. Stage 3 student feedback module overview questionnaire results

Students were asked additionally to consider the Arup engagement in DSES modules specifically. Over 75% were positive about their input into the module and felt more prepared to enter industry after undertaking it (Figure 3). Comments from the students demonstrated that the students valued the 'application of the sustainability issues in real case examples' and their engagement with several leading practitioners from Arup. It particular they found the 'sense of realism and change of pace' provided by the industrial lecturers extremely motivating'. Many commented that the input from Arup offered a much wider insight into available employment opportunities whilst enriching their group debates on thought provoking and often complex issues surrounding the completion of large projects.

Discussion groups with each Stage generally resulted in very positive responses to DSES as a whole, although some students admitted to being rather bewildered by the open-endedness of the tasks at first. Nonetheless, it is encouraging that all students have tended to perform well in the end and so have managed to overcome these challenges and develop strategies for solving complex problems, fulfilling another aim of the DSES modules.



(a) Did you find the input from Arup useful?

(b) Do you feel the lectures have prepared you better for the world of work after this module?

Figure 3. Student feedback on industrial engagement

4.2 Industrial Evaluation

In addition to Arup, a total of 15 employers from all sectors of the construction industry have been involved in the delivery and/or assessment of DSES in all stages. A summary document outlining the aims and content of DSES was produced and presented to the CEG Industrial Advisory Panel to the Civil Engineering Undergraduate Programmes in late 2010. Feedback was integrated into the DSES modules. Assessment criteria for DSES poster and oral presentations were developed in consultation with Andy Mace and the Industrial Advisory Panel. These were used for the first time during the JBM visit in 2012(more on this below) by both academic and industrial assessors of Stage 3 DSES presentations. At the same time, a questionnaire was completed by industrial assessors in order to understand motivations, perceptions of student work, students' readiness for employment and the value of DSES 3 as preparation for employment.

The employers' feedback rated the value of DSES in the preparation for employment as related more to 'softer' skills development than the technical content of the modules. In particular, the employers unanimously rated the students' ability to present and communicate at or above 'good' category. They also recognised the training that the student received in team-working and individual reflection as important to employability as well as their ability to think and express themselves innovatively. They appreciated the importance of these types of skills in an engineering context more than the students themselves, who had little or no experience of engineering practice and rated their own abilities far lower than the employers.

Results from the feedback survey indicated industrial involvement was largely motivated through personal contact with the module leader or with other members of staff in the School (via the Industrial Advisory Panel or directly via the professional bodies, e.g. the Institution of Civil Engineers). Engagement seemed to be driven primarily by the individual and their desire to contribute to the "wider good" element of engagement. The employers all felt that they were able to contribute to the young peoples' development; the students were attentive to the advice they offered and the employers were 'able to see new and innovative ideas which can be used in the UK' and were motivated by 'meeting and integrating with the potential engineers of the future'.

4.3 Joint Board of Moderators Feedback

A JBM Panel visited CEG in January 2012 to review the UG Programmes. The process involved a detailed review of the modules, teaching and learning provision, interviews with staff and students and inspection of student work. Reports and posters from the DSES modules were reviewed in detail.

In the feedback from the JBM panel, they noted that the School has a particular strength in terms of the teaching of design, sustainability and health and safety. In particular, their report stated:

"The Team agreed that, following the redesign of the programmes in 2008, the sustainability and design threads were strong and firmly embedded within all Stages. The students commented favourably on the suite of Design of Sustainable Engineering Systems (DSES) modules in Stages 1 to 3, which brought together many of learning outcomes achieved in other modules. The Team supported this view, and found the design projects to be of a good standard".

However, it was not all positive: they did not accept that materials teaching could be delivered effectively in Stage 2 of the Programme within DSES and insisted on a module dealing with materials be re-introduced.

5 Conclusions

We have managed to completely overhaul our Undergraduate Programme and now feel we deliver what we have set out to achieve: a Programme with sustainability integrated throughout the curriculum that challenges our academic staff and our industrial collaborators to deliver a whole system approach to sustainable engineering design that is needed in the 21st century. We are providing students with a broader awareness of the role of sustainability and sustainable development in the civil engineering industry, and with the skills to undertake sustainable engineering design. We are offering a Programme which has a distinctly 'Newcastle' flavour that reflects our research strengths whilst also complying with the requirements of the JBM. Particularly positive aspects of the experience have been:

1. Engagement of both teaching- and research-oriented academic staff through extensive consultation in the development process.
2. Gaining the commitment and leadership by the predominantly research-oriented Professoriate in designing the Programme and delivering research-led teaching.
3. Active engagement of leading sustainability practitioners from industry, the lasting legacy of the partnership with Arup and continuous updating to reflect best practice this affords.
4. Building on strengths in both teaching and research, particularly on the mutual synergies

Putting all this together, the most significant outcome is that we are now in a position where we have a strong management structure, academic and industrial engagement; we can continuously grow and update our Programme without the fear that it will drift away from our original vision. We recognise that we have initiated a large cultural change in the way that our UG Programme is delivered, and that we still have some way to travel before we achieve the level of integration across disciplines that is needed for the DSES approach to sustainable engineering design, and the elusive balance between the traditional technical subjects, and the broader, softer subjects that underpin sustainability.

6 References

Parkin, S (2008) Sustainability: still absent from higher education agenda, Proc. ICE, Volume 161 Issue 4 pp148