



Sustainable Engineering Systems – a new approach to civil engineering education

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Abstract

The increasing awareness and requirement for sustainability in undergraduate programmes has led to the development of a Design of Sustainable Engineering Systems (DSES) theme throughout the Newcastle University undergraduate programmes. This case study focuses on the development of the level 6 module in DSES. This module is a 40-credit design-based module that integrates all of the formal taught disciplines and is a vehicle for design-based education.

This “real” project focuses on the sustainable development of a large site in the city centre proposed by Arup. Industrial speakers (primarily from Arup) lectured on key elements of the design process and the integration of sustainability in a real context. The students were able (from an outline brief and literature) to develop a detailed client brief for the civil engineering aspects of the project, deliver a master planning solution and present this information in a concise and professional manner at a poster exhibition. Architectural elements of the designs were enhanced with the support of a practising architect. The audience of the exhibition was comprised of a number of industrial professionals, including those who had made inputs to the module, and members of the Industrial Advisory Panel for the civil engineering programme. In order to enhance the student experience of group working, integrate construction management concepts and to develop a “design project simulation”, a project management consultancy was used to evaluate and promote the student-led team development in the module.

Keywords: employer engagement, curriculum development, sustainability, design

Background

Driven by the benefits of interdisciplinary research, the School of Civil Engineering and Geosciences (CEGs) at Newcastle University undertook a root and branch review of its undergraduate civil engineering programmes in 2008. A vision was developed which placed civil engineering at the heart of delivering sustainable infrastructure and living environments in the 21st century and beyond. This strategy was endorsed by Parkin (2008), who identifies the failure of undergraduate engineering programmes to motivate students to meet the challenges of sustainability.

The undergraduate civil engineering curriculum at Newcastle is delivered through a thematic structure identified as the Newcastle Model (Figure 1). The merits of an interdisciplinary approach to design-based teaching have been highlighted by our external examiners as a core strength of our programmes. One of the primary mechanisms for delivering this integrated design approach is the theme of Design of Sustainable Engineering Systems (DSES) which is truly embedded at the heart of our undergraduate programme.

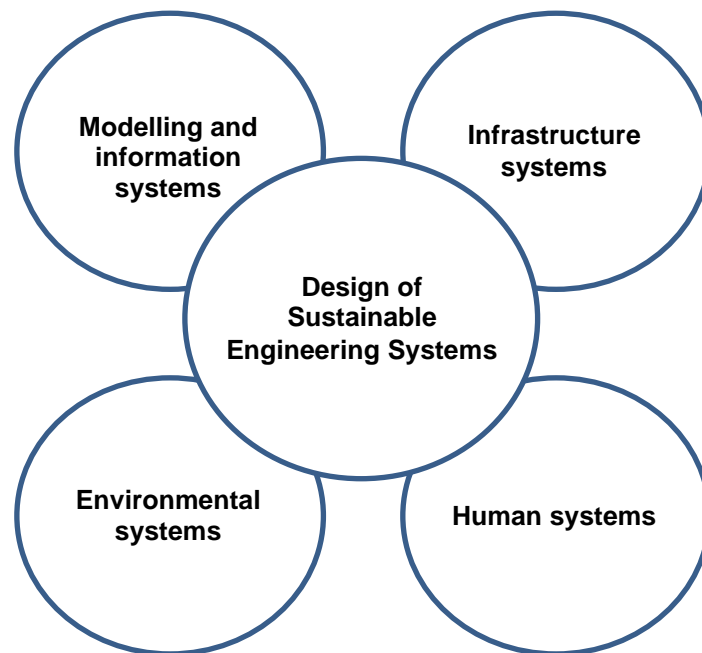


Figure 1. The thematic Newcastle Model

By building on the core interdisciplinary strength of our staff we have developed a platform which engages the students with the global challenges of sustainability through a series of highly focused design projects in each year of study. In the third year of the programme, with support from the National HE STEM Programme, a major industry-led sustainable engineering case study has been developed and forms the final piece of the DSES theme. The development of the theme through the stages of the programme has had the added benefit of enabling us to design a coherent set of transferable skills threads through the stages of the civil engineering (CE) programmes, thereby delivering students with enhanced employability and promotion prospects, in addition to sustainability skills.

Rationale

This case study demonstrates the added value of the engagement of employers in curriculum delivery, breaking down the traditional silo-based design approaches, and presents a discussion on how an undergraduate civil engineering programme can address the integration of key sustainability concepts within the curriculum.

The aim of this case study approach in the programme is to excite and enthuse the civil engineering undergraduates with a “real project” which focuses on sustainable civil engineering design, whilst better preparing them for employment, enhancing their self-development and preparing them for future leadership roles within the industry. This aim was achieved through an employer-led problem-based module which integrated the following concepts and elements:

- Interdisciplinary design elements of the CEGs curriculum
- Architectural concepts with civil engineering design
- Sustainability, whilst also engaging students with effective team working and self-development skills in preparation for employment.

Outside the scope of this case study, in the second semester, this approach will also allow the following to be embedded into the curriculum:

- Understanding of the live operational constraints as experienced by the construction industry
- Enhancement of the students’ communication skills using e-learning techniques.

The benefits of the project were thought to be two-fold:

1. The civil engineering and construction sector identifies a requirement to embed sustainability in all of its activities and will therefore benefit from a cohort of students which has the knowledge and skill-base necessary to deliver world leading projects
2. The students will benefit from the skills that they have developed, setting them apart from their peers. They will also benefit from their enhanced ability to work in a team, work creatively within limited time and budget constraints and develop self-learning awareness and planning for future professional employment.

The approach: technical module development and resourcing

Increasingly, graduates are required to work in multidisciplinary teams, demanding a particular set of skills that are ideally coupled with some experience of having worked in this type of setting. This demand on graduates needs to be reflected in programmes in the same way as they are designed to develop technical skills.

An opportunity arose during the restructuring of the programme to re-energise and re-focus all of the design threads in the programme into the DSES theme. The overarching aim of the DSES theme is to develop and build the skills of the students in the areas of communication of concepts, analysis and design in the built environment. This aim is achieved through a staged process of feasibility and options appraisal techniques on a regeneration project in Stage 1, an options analysis and detailed design of infrastructure in the built environment in Stage 2 and finally a large case study project which allows the integration of these taught concepts from client brief to output in Stage 3. The theme across all stages aims to develop awareness and understanding of systems and the inter-dependence of sub-systems dealt with in other themes of the programme, resource flows and life-cycles and sustainability principles in design, whilst integrating the knowledge and techniques developed in other themes within a single design case study.

In addition to academic development, the DSES theme also aims to develop the student personally and thus enable them to work efficiently in small teams, reflect on personal performance and define personal goals and develop skills needed in order to operate as project leaders in the gathering, analysis and comparison of relevant data from diverse sources.

The new programme (and therefore this design core) was rolled out in the school over consecutive teaching years: Stage 1 (2009/10), Stage 2 (2010/11) and Stage 3 (2011/12). The full realisation of the aims of DSES therefore only came about once the Stage 3 module was in place. A clear benefit of the completion of the three-year roll-out is that the student emerging from Stage 3, either as a graduate or entering into Stage 4 (level 7), has been provided with a comprehensive skill set in cognitive thinking and reflective learning as tools to achieve problem design.

The delivery of DSES with sufficient breadth and depth has been achieved through a reinvigoration of the staff engagement required for a fully integrated multidisciplinary module of this type. This has been led by a group of senior staff, with representation from across the disciplines, who have taken responsibility for hosting a series of “away-day” activities. They have also jointly designed the DSES modules and engaged staff in ensuring that they re-evaluate their own modules (coursework and exam expectations) to synchronise with DSES by supplying coherent coursework elements. This new module is a 40-credit module (one-third of a year of study), delivered over two semesters (20 credits per semester) and focusing on a large master planning project phase in Semester 1, followed by technically challenging and detailed civil engineering design in Semester 2.

To deliver the ambitious aim of the project, a project and company had to be identified to ensure that the background datasets were sufficiently robust to support detailed design. It was in these initial stages of the development of the module that personal contacts and collaboration proved essential. In 2011, Dr Glendinning completed a Royal Academy of Engineering Industrial Secondment in Arup’s Newcastle offices. As part of this secondment, she was able to work on a number of projects related to both her own discipline (geotechnics) and that of a new area of sustainable engineering. In addition, Andy Mace, Arup lead associate and head of the sustainability team, took up a Royal Academy of Engineering-funded Teaching Fellowship with the

objective of helping to design the DSES modules. It was these contacts which directly enabled the close working relationship required between Arup and Newcastle to develop this project.

The project selected was a regionally-focused community and university site. The winning consortium was a joint venture between an architect (MACE), engineering consultants (Arup), the local authority (Newcastle City Council), a regional development agency (ONE North East, now defunct) and Newcastle University to deliver a mixed-use site in the centre of Newcastle which was also to be an exemplar of sustainability.

Module resources: The gathering of the appropriate documentation for the module was a significant task and required time from the employer contributors and module leader to identify a suitable project, source project-specific information and sift through this to ensure both quality and appropriateness prior to release to the students. This information was sourced from a number of the collaborators for the site and ranged from simple company marketing information and tender documents through to technical desk study reports of the site and phase 1 ground investigation reports. These resources were made available to the students through the university's virtual learning environment.

Module delivery: The module was delivered over two semesters, focusing on a masterplanning element in Semester 1 (BEng and MEng students) and detailed design (MEng only) in semester 2. The module was delivered in a linear fashion during the semester and contact time was one three-hour session per week. The module was structured in Semester 1 order to deliver a specific element of the masterplanning process. This allowed 55% of the lectures to be delivered by industry during this semester, with a further 9% by staff outside the school.

The students also had the opportunity to attend an informal drop-in surgery session every week (staffed by the module leader) in order to support their technical solution development, if required.

The approach: transferable skills development

Enhancing and bringing to the fore students' employability skills was always a vision of the thematic design thread. Whilst many courses and modules require students to work in teams, few will provide feedback and support specifically aimed at supporting and developing group working. In order to develop transferable skills effectively, a closing of the feedback loop was required and was provided through individual student reflection and feedback elements within the module. The target transferable skills for this module are highlighted below:

Group working: It had been identified at programme strategy level that, although the course often requires the students to work in groups, the students receive little guidance on the mechanisms of effective group working, the resolution of difficulties experienced within a group and general feedback on the group process and how to improve it in the future. By developing and delivering the module in collaboration with a project management consultancy, the process of group working was formalised within the module. The module began with an interactive activity on the challenges of working in a group and general teamwork philosophy. This was outlined alongside advice on managing student teams and suggested techniques for conflict resolution. Under guidance and advice, the students were then allowed to select their working groups (within tight predefined guidelines) and were required to draw up and agree to a group working contract. This contract was signed by all members of the group and submitted to the module leader for ratification. Although this group contract did not carry any marks, a penalty was applied to any group which did not submit it on time. This session was followed up at the halfway point of the semester with an interim critique session with each group which focused on elements of the group working to date and reviewed the group contracts. These sessions were facilitated by the project management consultancy.

Communication strategy: As part of this module, it was a vision to extend a current communication strategy, initiated in Stage 1, into Stage 3 of the programme, with the involvement of staff from the university's central student service, the Writing Development Centre. In this module the writing development strategy was developed to include material for different audiences: technical, non-technical and public. This concept was commented on and highlighted as a point of

excellence during the recent programme accreditation visit. Furthermore, students were supported in the preparation of posters and leaflets by our in-house graphic designer.

The approach: methods, expectations and impacts

The expectation of the staff developing the module was the delivery of an exciting and technically challenging project which puts sustainability at the heart of civil engineering design and facilitates the students' group working and learning development. The learning outcomes of the module were assessed in five pieces of work:

- Group contract
- Group report for a non-technical audience (the client team)
- Group poster and leaflet for a public audience
- Group reflective report
- Individual reflective report and peer assessment appraisal.

These assessments reflect not only the development of the technical skills of the students, but also those personal development skills which, combined with excellent technical skills, will enable our graduates to become the future leaders of industry.

Group formation and contract: This element was the start of the process. All students were required to complete an online Belbin test which was designed specifically for this module. This gave all students an idea of the characteristics of their individual contribution to group work. The students were then asked to form groups of five or six within tight guidelines which focused on both students' areas of expertise and their Belbin survey type.

Individual reflective report: This report required the students to reflect on their personal performance against the group contract, personal development of skills and peer performance (against given criteria).

Limitations of the approach

The aim of this work is the development of students' ability to work in groups and for those groups to work together to solve a real case study. There were several issues which arose around both of these aims:

1. *Group working.* As with many of these aspirations, student satisfaction, particularly with allocation of marking, is the limitation. Whilst group work is excellent for the majority of students, the question which still needs to be adequately addressed in academia is *how do we deal with the minority for whom the process does not work?* Sometimes this may be due to a disengaged team member or to extenuating personal circumstances which impact on their contribution. In our experience, many of these problems only come to light as deadlines approach and, whilst we do employ a peer assessment policy to assist in managing the students' expectations, this is far from a satisfactory solution. The current approach to peer assessment in the school has been to allocate a proportion of marks for the submitted group activity and ask all members of the group to allocate a percentage contribution to each of their peers, detailed in an individual component of the work. Whilst guidelines are given as to how the peer marks should be allocated, the outcome is that staff redistribute these in each group in line with the agreed algorithm. This existing system (established by a working party in the school) has been trialled over the last two years and it is now evident that an unfair advantage could be gained by any group to which a solitary member makes no contribution (as their marks are then redistributed amongst their peers). This missing group member is unlikely to have significantly impacted on the final report mark, but the group assessment process could mean that a mark of 60% was awarded for the report and, as the missing member received 0%, the contributing individuals are able to achieve >60% for this component. Whilst this is a known limitation of the process, it is not acceptable (to either the student cohort or our own assessment ethics) to do nothing and

make no attempt to reward those students who fully engage with and contribute to the module.

2. *Effective delivery of a “real” project.* Trying to produce something that emulates the “real” process takes students well outside of comfort zones in which problems are well bounded and require clearly defined solutions. The challenge of producing a client brief for the students from a series of literature-based sources was too open-ended. Some of the student groups seemed to struggle to make assumptions and drive their project and clients forward; one student said that ‘to be given a blank canvas with a development was a really exciting proposition. A little more instruction as to the function of the site [*would have been nice*] but having seen other groups’ work in the presentation maybe our group should have been more proactive’. Mitigation methods were required to prevent potential failure and these generally took the form of surgeries, staffed by the module leader, to advise and lead the students through this process.

Despite the limitations, we feel that this has been an extremely valuable experience for both staff and students. In particular, comments from students were:

- ‘Choosing our own groups caused more problems than it was worth.’
- ‘Groups tended to form in friendships which cause issues in the module.’
- ‘Reflective process has been very useful at highlighting individual areas for improvement.’
- ‘Skills developed in earlier DSES1 and DSES2 have allowed an evolutionary process to take place in development.’
- ‘Got better at leading a team and working with a broader range of people.’
- ‘Understand the importance of the monitoring process in group work.’

Assessment

As detailed previously, the student assessment requirement was divided into two main components: a technical element to assess the development of a master plan for the client team and a reflective element to assess the personal development of the student and group.

The technical element consisted of a short group report written for the client team and the production and presentation of a group leaflet and poster for a public audience (Figure 2). The reflective element was assessed in both a group document and an individual report. The latter incorporated a peer assessment function for individuals to assess the performance of their peers in the project.

Employers were asked to be present for the poster and leaflet assessment session and to both question the students and mark the work produced. All of the feedback from the employers about the standard of students’ work was very positive.

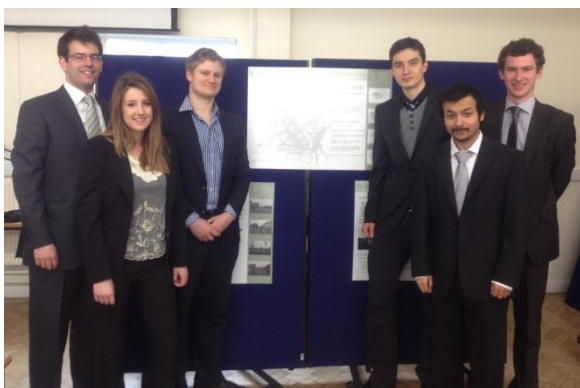


Figure 2a. Winning group for the master plan design



Figure 2b. Poster presentation assessment

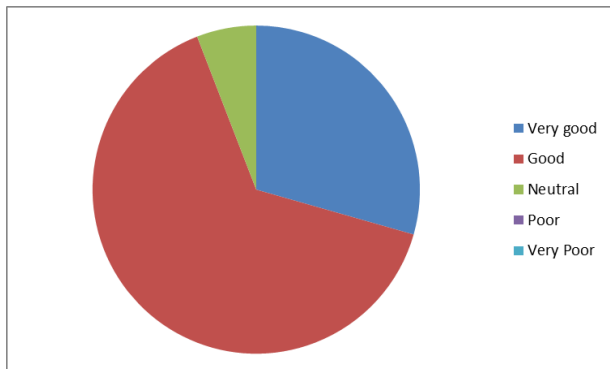
Evaluation

This module has created an exciting and stimulating challenge for the Stage 3 students. The following will evaluate the student and employer feedback results with regard to the technical and personal journey followed in this module.

Technical evaluation

The aim of the module was to engage the students in a professional context and develop the skills necessary to tackle a large multidisciplinary task with competence. Figure 3 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 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?

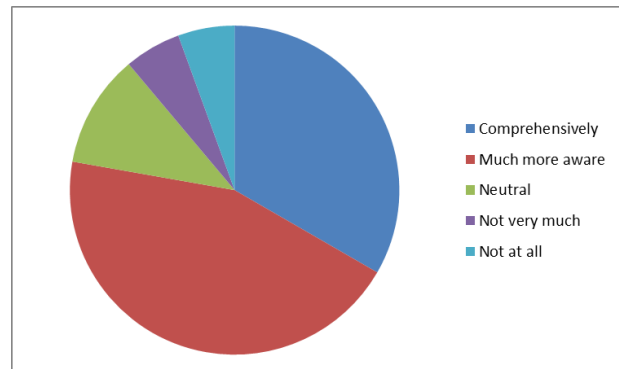
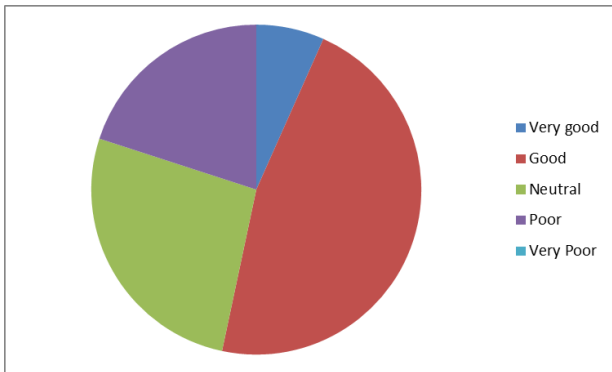


Figure 3. Student feedback module overview questionnaire results

Students were asked to consider this module in the light of employer engagement. Over 75% were positive about the industrial input into the module and felt more prepared to enter industry after undertaking it (Figure 4). Comments from the students ranged from 'enjoying the application of the sustainability issues in real case examples' to feeling that 'industry delivered the materials as well as the lecturers did'. The latter comment demonstrates that industry is able to both support the academics and deliver the material to the students to an equal or better standard and thus should ensure consistency, quality and appropriateness with regard to the difficulty level at all stages of design input. Overarching opinion was that the students ultimately saw the engagement of several leading consultants from Arup as a positive benefit to the module and that they 'gave a sense of realism and change of pace compared with normal lecturers'. Many commented that the input from industry offered a much wider insight to available employment opportunities and enabled the thought provoking and often complex issues surrounding the completion of large projects such as these to be debated within their groups.

a) Did you find the input from industry useful?



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

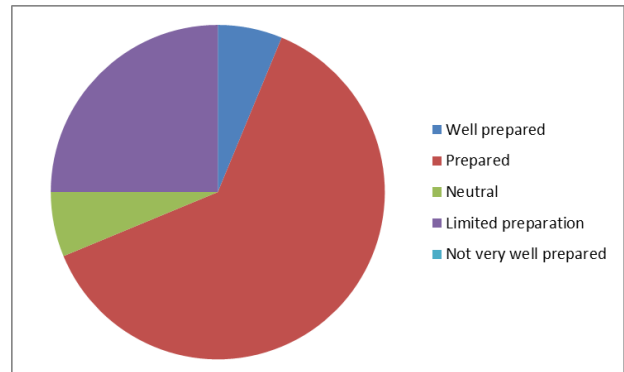
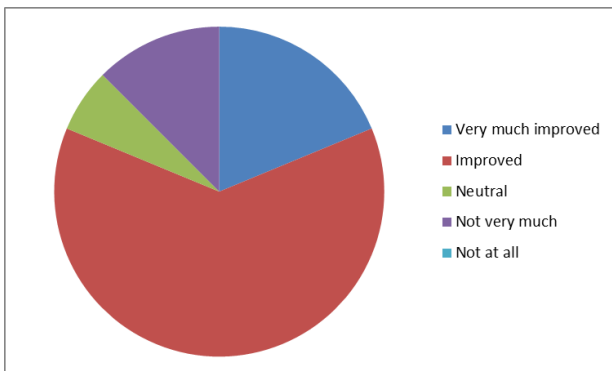


Figure 4. Student feedback industrial engagement results

Personal evaluation

In line with the personal development DSES thematic aims, the students were asked to reflect on the group working strategy they had experienced and consider whether they felt it had improved. Feedback questionnaire results were very positive: 88% of the student cohort felt that their group working had improved as a result of the interventions in this module (Figure 5) and 93% felt that the use of individual reflection in the process was a good way of developing their group working skills.

a) Do you consider that your approach to group working has improved in this module?



b) Do you feel that the approach and requirement to reflect on your individual contribution has been useful?

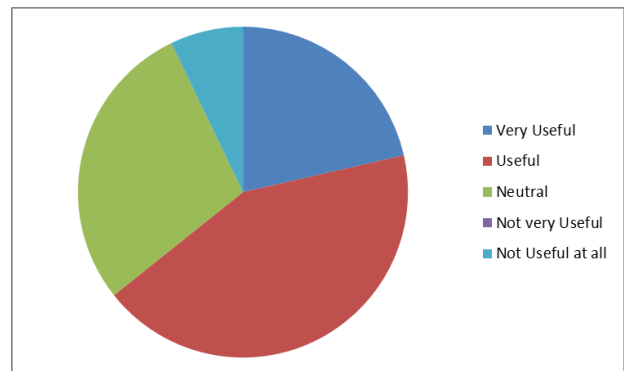


Figure 5: Student feedback on reflection and group working in DSES theme

The feedback on the communication development was a little more mixed and, whilst the employers unanimously rated the students' ability to present and communicate at or above the 'good' category, the students themselves did not seem to recognise that this was taking place. The students enjoyed the formal poster presentation session and welcomed the opportunity to display their work to the employers and academics who were not directly involved. However, they also found the request to address a non-technical audience challenging and, whilst they may not like this element, this was not evident in the other assessments. It is therefore perceived that this is more likely to be a lack of confidence of the students in their abilities or a student perception that this aspect is not valuable to their development, rather than a concern about the module.

Employer engagement and feedback

A total of 11 employers from all sectors of the construction industry were involved in the delivery and/or assessment of the module. As evidenced by feedback surveys, the engagement of the

employers was generally 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, i.e. the Institute of Civil Engineers). All contributors were at a level within the company where they were able to commit some time to the industry-academia relationship. The time commitment varied from four to 16+ hours over the course of the semester. This time was split into all elements of engagement through preparation, delivery and assessment activities. According to the feedback, employer 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’.

Summary

The development of this module has brought to fruition an undergraduate civil engineering programme which is both visionary and thematic in its approach to infrastructure systems engineering and preparing the graduate with the skills required to face the challenges of the 21st century. The module has developed new links with industry through engagement at all levels of the module. This engagement was primarily initiated by the use of a Royal Academy of Engineering-funded placement for the academic and an employer Royal Academy of Engineering Teaching Fellowship and is now (subject to industry economics) embedded within the programme. It has been enhanced by strengthening links and re-engaging members of the Industrial Advisory Panel for the good of the undergraduate programme. The module leaders, through the restructure of the programme, have been “forced” to evaluate the module’s assessment and relevance and this has enabled a true integration of modular disciplines into the large design methodology.

The sector has identified a requirement to embed sustainability in all of its activities and will therefore benefit from a cohort of students which has the knowledge and skill-base necessary to deliver world-leading projects. This module has demonstrated that the graduates from Newcastle are aware of sustainability concepts and frameworks and their relevance to the construction industry. The students have also benefited from the skills that they have developed in setting themselves apart from their peers through their enhanced ability to work in a team, work creatively within limited time and budgets and develop self-learning awareness. This is all excellent planning for future professional employment.

Further development

Semester 2 of this module builds on all of the skills developed by the students, whilst increasing the disciplinary element as they work in larger teams and produce detailed designs of elements in the master plan for the site. This also allows the leaders of the design modules to embed discipline-specific information in their module and allow the design of this to be implemented through DSES3.

It is anticipated that this module will continue into the foreseeable future as a key element of the re-designed undergraduate programmes. All of the teaching materials have been developed and have been stored. These have been made available via the BlackBoard platform. Newcastle lecturing staff have been able to benefit from the sessions delivered by external contributors, thus increasing their skills and enabling future delivery of topical information as necessary. The integration of key industrial staff is anticipated to be continued as all of these staff have other input into existing discipline-specific modules in the school and are therefore developing a long-standing relationship with the school. Within the university, a memorandum of understanding is in place with Arup to formalise a wide-ranging relationship that will enable a long-term partnership to be developed.

References

Parkin, S. (2008) ‘Sustainability: still absent from higher education agenda’, *Proceedings of the ICE - Civil Engineering*, vol. 161, no. 4, p. 148.



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