Civil Engineering Design Realised through Case Study Focussed Problem Based Learning

Jean A. Hall[1], Sarah Dunn[1] and Stephanie Glendinning[1]

[1]School of Civil Engineering and Geosciences, Newcastle University, Newcastle, NE1 7RU

jean.hall@ncl.ac.uk

Abstract

Lecturers of todays' engineering students aspire to have '*graduates who are engaged with the global challenge of engineering a sustainable future for the planet*'. This ambitious vision can be realised through the placement of Civil Engineering at the heart of delivering this sustainable infrastructure and living environments into the 21st century and beyond. To meet this challenge as a civil engineer, the undergraduate programme of training must evolve from the traditional narrow remit of devising a chosen solution from amongst several purely technical options to that of a much broader whole system approach. This approach can account for the increasingly complex interdependencies and interactions between the built environment, the natural systems and cycles that sustain life on Earth with consideration to the pressures and demands that human populations and networks place on these systems.

At Newcastle University, the School of Civil Engineering and Geosciences (CEGs) has engaged in this vision and revamped the undergraduate civil engineering programme to be centred around a systems-based integrated course with sustainable development at its core, thus engaging with the environmental, social and economic dimensions of this unifying concept in the design, implementation, and rehabilitation of all civil engineering interventions within the Earth system. It challenges the 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.

This paper will present the background rationale and vision of the thematic undergraduate programme focussing on the delivery of the Design of Sustainable Engineering thread through the 3yrs of the undergraduate programme. It will demonstrate how the use of case study focussed, problem based learning pedagogies has developed both the design and transferable skills base of the students. It discusses the interventions used in the teaching methodology in these modules to ensure that feedback loop is utilised whilst ensuring the required depth of learning takes place for these professionally accredited programmes.

1 Introduction

The knowledge development of students throughout engineering degree courses is well considered in curriculum, course and module design. However, the skills development of the same students is often overlooked. It is often assumed that students will automatically know how to write an engineering report, how to give a presentation to a non-engineering audience and how to work effectively as a team, to name but a few examples.

In this paper, we develop a method to understand the current skills development in undergraduate students and show how this can be correlated with the required skills level of graduates. From this knowledge, methods to map the skills development throughout a degree programme are created. We also develop 'interventions' which aim to address any lacking areas of skills development in the programme. A flow chart outlining this method is shown in Figure 1. We show how this method can be applied to existing degree programmes by mapping the skills development of undergraduate Civil Engineers at a UK Russell group university.

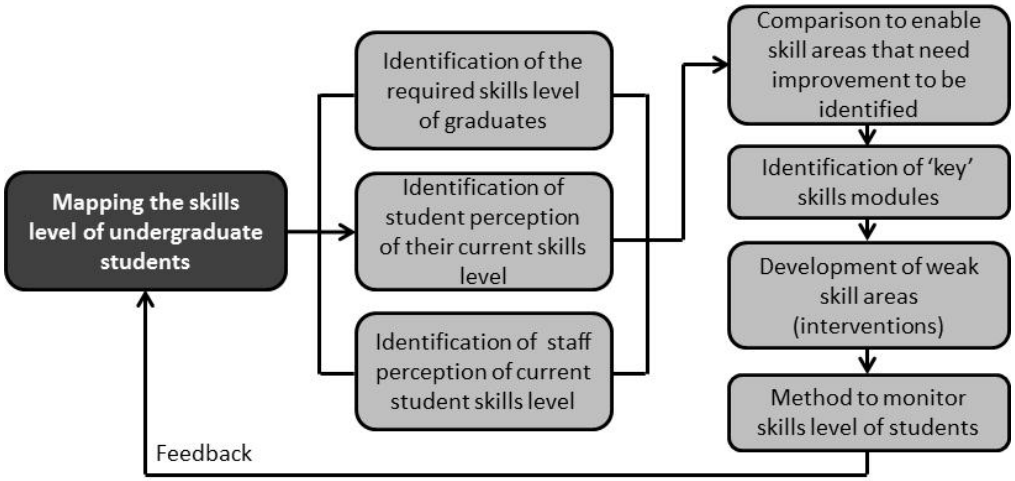


Figure 1: Flow chart showing the outline method developed in this paper to map the skills level of undergraduate students.

2 Identifying Required Skill Level of Graduates

The knowledge level of undergraduate Civil Engineering students at the study university is well mapped throughout the three years (Stages) of the degree programme. The current curriculum structure at the study university consists of four main areas of knowledge learning in the degree programme, the programme and the rationale of this framework are discussed in Glendinning et al, (2013). However, less mapped is the skills level for the same students. Currently the Graduate Skills Framework (GSF), consisting of 4 main headings and 34 sub-headings, is used to map whether a particular module either '*practices*' or '*assesses*' each of the 34 identified skills. However, this mapping is done independently (i.e. by each module leader for their specific module) and using this system it is not clear whether the skills level of the students' progresses continuously throughout each Stage and indeed throughout the degree programme (i.e. are they taught how to write an engineering report before they are assessed on this skill?). The complexity of the graduate skills framework is one of the main reasons why this progression is unclear and has yet to be mapped comprehensively at a curriculum level.

To enable the skills progression of students throughout the degree programme to be mapped we have simplified the GSF, reducing 34 skill areas to 13 (these 13 skill areas can be seen in Figure 2). This was achieved through interviews with current teaching staff members and industrial advisory panel members to identify what they perceived to be the main skills for undergraduate Civil Engineers (for example the GSF has *foreign languages* as a skill, whereas this is desirable it is not essential in this course).

To identify the level of skills development that graduate engineers are expected to have data has been gathered from the QAA (Subject Benchmark Statement), EC (both the UK Standard for Professional Engineering Competence and the Accreditation of Higher Education Programmes) and the JMB (Guidelines for Accreditation of MEng Degree Programmes). This data has been mapped onto the Modified GSF to clearly highlight the skills that are most required (Figure 2). The area that receives the most attention is the team working skills, with BEng graduates being required to be '*capable*' and have '*knowledge of management techniques*'; for the MEng gradates this skill is expected to increase, with graduates needing to be able to '*lead and manage teams*'. There are also three other areas that are highlighted in all four guidelines: '*Independence*', '*Appreciation for Civil Engineering Related Costs*' and '*Innovation and Creativity*'.

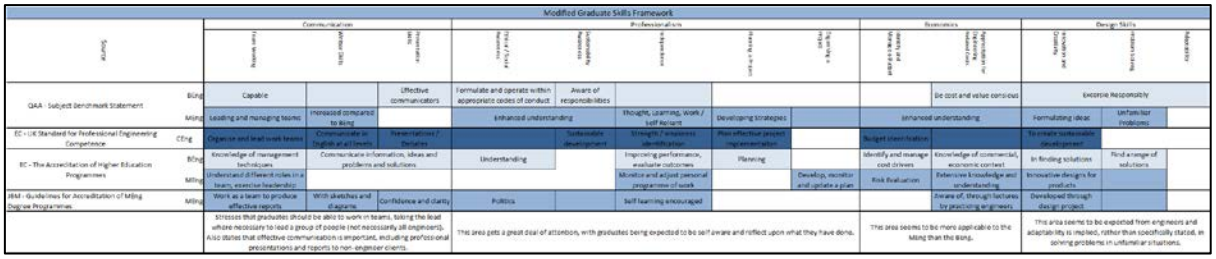
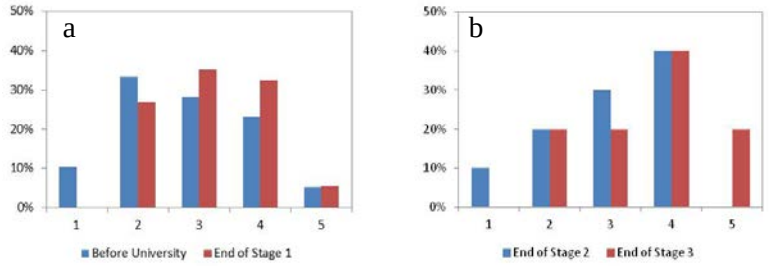


Figure 2: Mapping required graduate skills onto the Modified Graduate Skills Framework

3 Identification of Current Skills Level of Students

To enable the current skills level of students at the study university to be identified, students in stages 1 and 3 were asked to complete a questionnaire, sectioned into the modified GSF sections. The students were asked to reflect on the skill level they perceive that they have for each statement; thus allowing the perceived skills progression of the students to be mapped. Due to space limitations in this paper we are only able to present, and discuss, the detailed results for to of the skill areas, however, a summary of the main findings are discussed later in this section. Figure 3 shows the results for the *presentation skills*, it can be seen that there appears to be a wide range of abilities of students entering university. Most students answered that they were '*Not Confident*' at presenting when they started university, but this had improved to '*OK*' by the end of Stage 1. However, there are still a reasonable amount of students who feel they lack in presenting skills. This improves as the students go through the course, with the majority of Stage 3 students answering that they are '*Reasonable Confident*' with their presentation skills when they are at the end of the stage. However, there are still a number who are '*Not Confident*'. As this skill heading encompasses writing and giving a presentation to different audiences it could be that these students find giving a presentation to be 'out of their comfort zone' and this is reflected in how they perceive their skills level.



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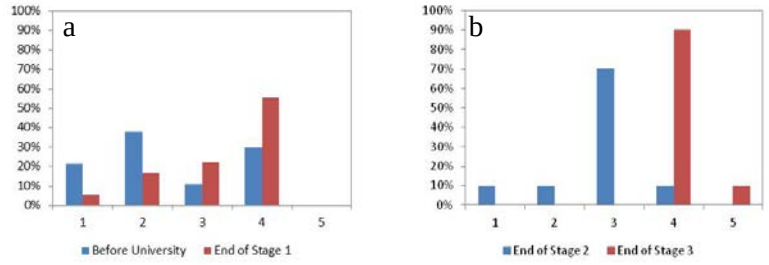
1	Poor
2	Not Confident
3	OK
4	Reasonably confident
5	Great

Figure 3: The results of the questionnaire for Presentation Skills, showing the results for (a) the current Stage 1 students and (b) the current Stage 3 students. The table (c) shows the meaning of the numbers on the x-axis in (a) and (b).

There is a considerable improvement in the development of the ethical / social awareness of the students in Stage 1, most are '*Partially Aware*' of this when they start university, but after completing Stage 1 are '*Generally Aware*' (Figure 4a). This does not seem to change throughout the degree, as students who are leaving Stage 3 are also '*Generally Aware*' of ethical / social awareness (Figure 4b). At the start of Stage 3, it is interesting to note that the ethical / social awareness of the students is lower than that of the students at the end of Stage 1. One possible explanation is that during Stage 3 the students have found that this skill area is more detailed than they perhaps perceived at the start of the year and so have altered their view of their skill.



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1	What is this / Never heard of it
2	Partially aware
3	OK
4	Generally aware
5	Know it all

Figure 4: The results of the questionnaire for Ethical / Social Awareness, showing the results for (a) the current Stage 1 students and (b) the current Stage 3 students. The table (c) shows the meaning of the numbers on the x-axis in (a) and (b).

The results of the questionnaire, from Stage 3 students (considering the end of their current stage) have been compared to the skills level required by graduating engineers, as summarised in Figure 2 (Table 1). It is worth noting that these results have been modified to account for the emphasis placed on the skill. For example, students responded to being '*reasonably confident*' at presentation skills, although there is a large spread in the results obtained (many students responded as '*not confident*'). Therefore, as this skill has a large emphasis placed upon it by the professional bodies (including: JBM, QAA, EC), it has been classed as an area which needs improvement, ensuring that all students are at least confident with the skill.

Table 1: Showing the areas that the degree programme needs to improve / is doing well, using the results of the end of Stage 3 students and skill level expected by graduating engineers (as set out in Figure 2).

Needs Improvement	**Minor Improvement Needed**	**Sufficient**	**Good**	**Excellent**
Presentation Skills	Written Skills	Team Working	Adaptability	Ethical / Social Awareness
Independence	Problem Solving	Planning a Project		Sustainability Awareness
Identify and Manage a Budget		Organising a Project		
Appreciation of Civil Engineering Costs				
Innovation and Creativity				

From Table 1 it can be seen that there are several areas for development in the degree course; these areas tend to be those specifically highlighted as being 'important' for graduate engineers in Figure 2.

Following these results, 'key' members of staff were asked to score each of the 13 skill areas, indicating whether each skill either '*needs improvement*', '*needs minor improvement*', is '*sufficient*', '*good*' or '*excellent*'. These scores relate to the current student at the end of Stage 3 and the results are shown in Figure 3.

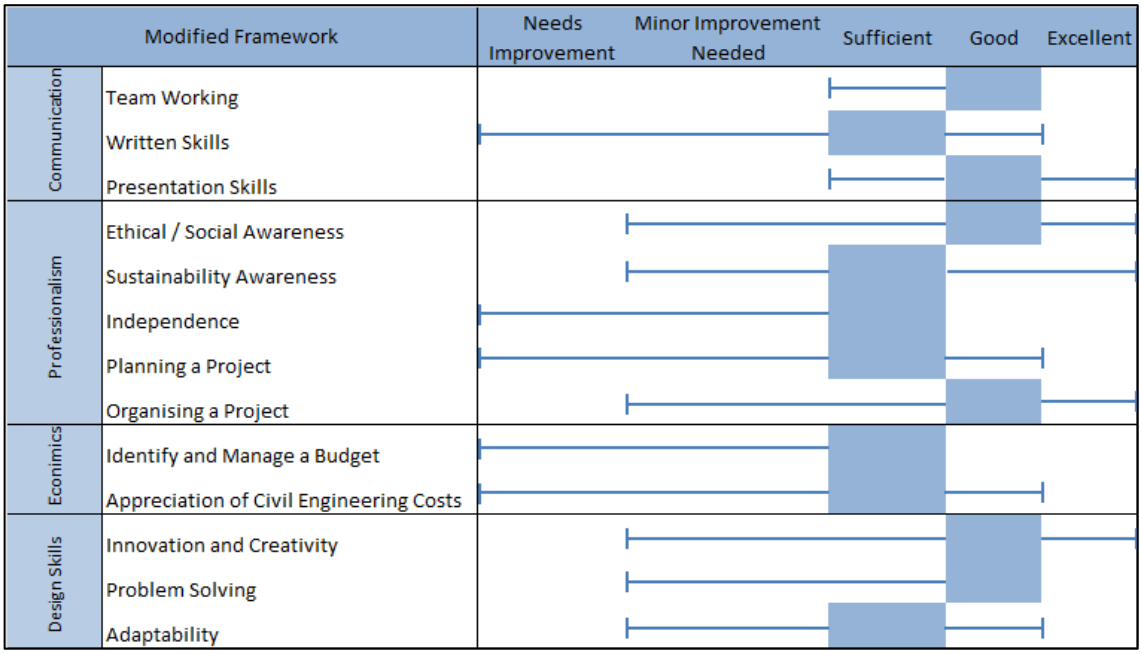

Figure 2: Scores given to each skill area by 'key' members of staff. The shaded blue area indicates the most popular answer given and the two lines either side show the range of answers given by staff. For example, for the Team Working skill most staff answered that this was '*good*' but there were also some members of staff who indicated this skill to be '*sufficient*'.

It is interesting to note that most staff members perceive the course to deliver graduate students with either '*sufficient*' or '*good*' skill levels in all of the graduate skills. The skill areas identified by some staff members as needing improvement tend to be those also identified by correlating the results of the Stage 3 students (at the end of the Stage) and the guidelines for graduate engineers as needing improvement (Table 1).

4 Identification of 'Key' Skills Modules

To ensure that the skills development of students increases throughout the degree programme, 'key' skills modules need to be identified. Identifying these modules will ensure that they are not adversely affected by the later interventions to improve the delivery of skills learning throughout the degree programme. These modules will also be used to form the basis of a skills delivery framework. Within each of these modules, module leaders are free to change and evolve their module annually subject to consultation with the appropriate stage tutors. These stage tutors monitor the type and frequency of the assessment of each skill area and ensure that the mode of assessment is both varied and dispersed over the year.

The students were asked to identify what they perceived to be the key skills modules in the degree programme as part of the questionnaire. Most students answered that the 'Design of Sustainable Systems' modules were the most useful at skills development. These modules are in each stage of the degree programme and are unique to the study university; they aim to 'pull together' the knowledge learning of the students in the other modules and apply this learning to an engineering problem (for example, the master plan for a new sustainable development). As there is little, or no, additional technical knowledge learning required by the students in these modules, the focus can be placed on skills learning. The modules normally culminate in a detailed presentation (either oral or poster

display) targeted to a specific audience in each stage. The students also identified the 'Human Systems and Impacts' and 'Engineering Ethics' modules as other key skills modules.

5 Development of Weak Skill Areas (Interventions)

The Design of Sustainable Engineering (DSES) thematic thread has been identified as a key area, by the students, for skills development. In order to develop students skill areas through *introduce, practice* and *assess levels* the course must be viewed as a whole. Figure 6 shows how the design thread and associated skills are developed through the programme with varying group size. The students work in small (<5 students) and large (>12students) groups throughout their 3 yrs. In the final semester of Stage 3, the students are expected to have the skill set to be able to manage and work within a very large group (≈ 25 students) however within this large group, the students will work in small discipline specific sub-groups to complete the elements of the detailed design of a large city centre masterplan project.

		Stage		
		1	**2**	**3**
Semester	**1**	**Small Group** (Detailed Design)	**Large Group** (Professionalism, Project Management)	**Small Group** (Conceptual Design)
	2	**Medium Group** (Conceptual Design)		**Very Large Group** (Detailed Design)

Figure 6: Development of group-working philosophy throughout the DSES modules

However it is not enough just to 'put' the students into groups and expect the skills development to be successful for all students, just because students are working in groups does not mean that they have developed their skills to a successful standard. However, through an understanding of skills delivery, curriculum mapping and 'interventions' this can be achieved.

There is a desire that these design projects, at all Stages, should integrate both existing knowledge learning and mimic industry as far as reasonably possible. This desire poses a series of open-ended pedagogical questions which need to be addressed.

- *How do we ensure a skill is introduced before it is assessed?*
- *How do we measure success in a skill level?*
- *How do we plan an intervention into the programme to correct/enhance a skill development?*

Although all of the DSES projects require a suite of skills to be utilised, each of the Stages focusses on different set of skills to develop.

Stage1 – This is the initial opportunity to begin to develop communication and groupworking skills in earnest. The students are also introduced to the concept of reflective learning and are asked to complete two reflective learning reports at the end of each semester. A series of theory lectures throughout the year support these practical activities. This Stage includes four main skills learning exercises:

Residential experience: The students begin this phase of learning with a short overnight residential experience in their first week of starting the course. They are asked to work on short practical problems in teams of 6 throughout the fieldcourse. These teams are changed every 3

hours and therefore the students rapidly focus on the requirements of the task whilst getting to know their cohort in an unusual setting.

Quick-fire Design: After this residential experience, an afternoon of quick-fire big-picture design workshops are completed within student groups and are all designed to get the students thinking about the bigger civil engineering picture. Feedback and debate is provided through a series of 2 minute student presentations to staff and fellow students.

Bridge Design: For the initial task, students work in groups of 3. Each group is assigned a client (post-graduate demonstrators) to whom they report on regular occasions and through this task the students are introduced to a meeting environment. This introduces the key skills of chairing a meeting, assigning group actions and developing a project whilst receiving detailed formative feedback as a group from the client. At this stage, the clients are running the agendas for these meetings. The assessment for this element is a short report, calculations and a group reflection on their group-working skills on which they will receive both formative and summative feedback.

Conceptual Design task: In semester 2 the group size (from the Bridge Design task) is increased, aiming to introduce project management concepts within the group. Every fortnight the students are given a specific client objective and are asked to present updates to their clients at 3 week intervals throughout the semester. This is key to the group management strategy of the module staff and allows for early intervention if required. The final assessment for this phase is a coherent design report, a formal presentation to a professional audience and an individual reflective report.

Stage 2 – the key skill development focus for this Stage is project management and development of log books. The students are placed in large design groups to complete a yearlong design task. They are required to keep log-books, throughout the process which are assessed at regular intervals to allow development learning to occur. The students will still be working on their group skills and communication skills throughout this year.

Stage 3 – this stage has 2 key tasks delivered in each semester. In semester 1 the students are part of a small group (<5) developing a masterplan for a site in close collaboration with industry. Thus the key focus for this semester is developing professional practise and communication. The communication thread (verbal and non-verbal) is further developed with a series of presentation outputs delivered to a varied audience (non-technical and technical). In semester 2, the 'winning' masterplan, voted for by a professional panel, is developed into detailed design. It is this project which is designed to closely mimic industry operating conventions as the students are in a very large design group (≈25) with small discipline-specific sub-groups (≈4). The focus of this project is to assess the students technical knowledge and ability to convey that to a client through a detailed design report and an individual interview. The students must also be able to project manage the design process, meet deliverables for each other and communicate this information effectively.

Interventions have been introduced within the programme to address specific skill development which the students perceived as lacking. Table 2 shows a sample of a larger table, which identifies all MSF areas, and identifies the expected skill level at the end of any stage and addresses appropriate interventions made to ensure each MSF objective is made. From literature and student interview feedback, it is apparent that effective signposting of skill development builds confidence within the cohort as does a combination of '*closing the feedback loop'* in assessment exercises and reflective learning from individuals.

Table 2: Showing a section of a larger table addressing the MSF objectives and anticipated interventions within a stage.

Skill and MSF objectives		**Expected Skill Level at the end of Stage**			**Interventions Employed to Enable Skill Progression**
		1	**2**	**3**	
Communication	Team Working	Can work in a team and reflect on strategy		Able to work in multidisciplinary teams	Introduction of team roles and use of a client contract
	Written Skills	Can write a factual report	Also able to write an interpretive report	Also able to write for different media (i.e. marketing, posters for public audience)	Regular practice and feedback with key points to improve in subsequent reports
	Presentation Skills	Able to write and present a short presentation (either as individuals or in a group)	Able to present technical information to an engineering audience	Can present to a varied audience (including non-engineers)	An introductory presentation showing the do's and don'ts, as well as regular presentation practice

6 Method to Monitor Skills Level of Students

Unlike knowledge learning, transferable skills are inherently difficult to monitor and often rely on the perception of students to identify current skill levels. At the study university a multi-fingered approach is used to manage the student and staff perception of skills development and to identify potentially weak areas which may require interventions to address. These approaches include:

- Questionnaires through student response system – these are designed to challenge the students perception of skill development and to signpost where this development occurs.
- Focus groups– these are conducted by the stage tutors to gain detailed feedback from a selection of the students on specific areas
- Module feedback specific questions – as part of this university central process, specific questions identifying the key engineering skills e.g. Design are evaluated
- Monitoring of changes to the curriculum and assessment framework for the programme – this is implemented through a programme management group consisting of the degree programme director and stage tutors and is held annually

What is of interest is the skills level of recently graduated students, however this can be difficult to obtain, as these students have left the host university and contact may be difficult to maintain. At the study university this problem is addressed through discussion with high profile graduate employers and through these discussions contact with recent graduates, who work for these employers, can be maintained. The graduates, and their employers, are asked specifically about their perceived level of graduate skills after graduating from the programme and if they feel that they are lacking in any skill areas. Members of university staff, involved in the delivery of the programme, are also asked as to their opinions of the skills level of recent graduates. In particular, feedback from staff involved in the supervision of dissertations is sought. At the study university, this feedback is used to inform future decisions regarding the direction of learning in the programme. For example, a new module was

introduced in the 2012/13 academic year (*Hall et al. 2013)* and aims to address the problem solving and adaptability skill areas.

7 Conclusions

In this report, we developed a method which can be used to map the current skills level of students in an undergraduate degree programme and have compared this to the required skills level of graduates to enable weak skill areas to be identified. Interventions to improve the skills level in these weak areas have been discussed, as well as methods to ensure that the skill level of students is maintained in the future. We have applied this method to an undergraduate civil engineering degree at a Russell group university.

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