Exploring first year undergraduates' perceptions of conflicting parameters and complexity in civil engineering through three learning experiences

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Abstract

The role of, and need for, higher education to create and promote a holistic approach to engineering is a key part of developing sustainability literacy amongst future engineers. Whilst development of sustainability literacy is a continuous educational and professional requirement of engineers, the first year of higher education is a particularly sensitive period. This paper examines three different but linked exercises used to encourage students to engage with the conflicting parameters and complexity present in civil engineering, whilst supporting the broader first year student experience.

From the first exercise (learning from experience), students' written, qualitative commentaries of an exploration of their campus locale showed an ability to not only identify stereotypical civil engineering issues such as construction trends over time, but set these against economic and social demands and impacts at a city-scale.

The second exercise (practice-based learning) asked students to rank the importance of components of a sustainable community as a civil engineer, and then rank them separately as a citizen. The rank orders of importance were found to be reversed, highlighting the conflict and complexity present in community-scale civil engineering.

In the third exercise (engineering by doing), ten groups of approximately ten students were led through a discussion around a systems approach to engineering and the impact of civil engineering infrastructure development. The groups were then challenged to identify infrastructure that, should we have the opportunity to "start again" on a new Earth-like planet ("Earth 2.0"), they would forego so as to avoid the negative impacts. Although no group succeeded in unanimously agreeing on some aspect of infrastructure they would not develop again, there were clusters of consensus and each group demonstrated an understanding of cost:benefit tradeoffs and compounded impacts of infrastructure development up to a global scale.

These exercises provide students with an understanding of hard-to-measure boundary conditions, more informally "context", that can surround the technical excellence at the heart of civil engineering systems. The exercises help both students and teachers to assimilate the concept of civil engineering complexity at a range of scales, and provide a reference point from which students can move forward to explore the concept of sustainability, particularly the need to consider social, economic, political, and technological issues as well as the natural environment. Finally, the exercises support an undergraduate student's first year experience.

1 Introduction

For 19th Century engineers, the Earth was a source of resources and a receptor for waste. In the 21st Century, the negative and/or far-reaching impacts of the work of civil engineers are coming to the fore. The increasing consideration of impacts and their causes, as opposed to simply meeting demand, has forced civil engineers in to taking a Systems approach; one where technological systems are considered alongside human/societal systems to create sustainable engineering solutions (Allenby, 2000; Hall & O'Connell, 2007; Royal Academy of Engineering, 2007; Royal Academy of Engineering, 2011). Indeed, the Institution of Civil Engineers (2012) is embracing the concept of sustainability with its vision: "Civil Engineers are at the heart of society, delivering sustainable development through knowledge, skills, and professional expertise". Sustainability includes complex, fragmented and diverse challenges to the civil engineer (Parry, 2006; Willets *et al*,. 2010) and his or her influence upon decision makers, environments and communities (Fenner & Jeffrey, 2011; Laws & Loeber, 2011).

In an attempt to ensure that holistic sustainability literacy, i.e. a wide range of skills that empower people to act and reflect on issues of sustainability (Stribbe & Luna, 2009), is developed from as early as possible in their course, first year civil engineering students at Newcastle University complete a module designed to introduce human and societal (i.e. non-technical) aspects of civil engineering, and also the basics of systems theory as a tool to help. The principles from this module are further developed in a co-requisite multidisciplinary design task module.

Whilst some aspects of sustainable civil engineering systems can be conveyed using didactic methods, others, particularly the non-technical aspects, can be difficult to capture and calibrate and they remain an ambiguous concept (Jowitt, 2004; Valdes-Vasquez & Klotz, 2010). The double challenge posed by sustainability to both paradigm and provision in higher education (Sterling, 2004) is evident when trying to stimulate consideration of human and societal aspects in a civil engineering curriculum.

Alongside the challenge of developing and promoting sustainability literacy is that of student engagement. Improving student engagement is a rising priority in higher education for a number of reasons including end of course student satisfaction surveys and the importance of student retention (Willis, 2008).

This paper describes three exercises and pedagogies that are designed to help both students and staff to explore the complexity of civil engineering and its role/importance to sustainable development. A description of each exercise is given, along with a rationale for how they support both development of sustainability literacy and the first year student experience. Results from, and observations of, student work are presented. There is significant scope for further work from these exercises and some options are discussed.

2 Three learning exercises/experiences: rationale and description of pedagogies

2.1 Providing engaging learning experiences in the first year of study

A student's early experiences are widely acknowledged as crucial to supporting both satisfaction and retention and Bovill *et al.* (2011) present eight principles and guidelines for curriculum design to engage and empower first year students. Of the eight, the following two were addressed by the three exercises presented in section 2.3 below: "Students should be enabled to develop the abilities required on graduation"; and "Engaging learning experiences should be generated."

With regard to abilities required on graduation, Steels (2011) notes a significant gap between academic education and the workplace learning environment that a graduate civil engineering student will find themselves in when starting out on their initial professional development. Advocating an approach of "learning from experience", Steels describes techniques for new graduates to explore and reflect on judgements they and their colleagues make in trying to balance six conflicting civil engineering parameters: Resources; Environment; Maintenance; Safety; Acceptability; and Function. The exercises introduced these parameters both explicitly and implicitly to the students.

In relation to engaging learning experiences, Willis (2008) poses questions to prompt reflection on first year teaching and learning environments, amongst them "How many practical experiences are offered in the first semester?" and "Are students given the opportunity to work in teams?". One might view none or all three of the exercises as "practical" but, at the very least, the three activities differ from a potential timetable staple of lectures. Working in teams takes place in all three activities.

2.2 Student perceptions of learning

Tudor *et al*. (2010) present a theoretical framework for considering students' perceptions and approaches to learning. By placing the exercises early in the students' first year experience, using the campus locale as a classroom, and using group work, the exercises support three of the five inputs to student perceptions of learning, specifically:

- Institution characteristics:
    - City centre campus location; and
    - Exercises relate to the University's world leading and internationally excellent research in Earth Systems Engineering and civil engineering;
- Relationship with peers: through group work; and
- Assessment and feedback: Skinner and Mort (2009) acknowledge that engineering students can be poor in areas such as writing (owing to their strengths lying in other areas e.g. numeracy), or may be reluctant to engage with the skill. The Town Trail exercise (see 2.3.1 below) gives an early opportunity for students to present some written work and receive feedback.

2.3 The exercises

The following exercises support both student learning about complexity, and provide a positive first year experience:

- The Town Trail;
- Earth 2.0 seminar - a discussion and debate; and
- Sustainable Community priorities.

They are delivered in Semester 1 of the first year of a suite of civil engineering degree courses comprising MEng Civil Engineering, BEng Civil Engineering, MEng Civil & Structural Engineering, and BEng Civil & Structural Engineering. This paper focuses on the delivery of the exercises in the 2012-13 academic year. The class size was 90: 72 male, 18 female; 70 UK, 3 EU, 17 International.

The overarching vision for the exercises was to stimulate thought in students about "why" civil engineering infrastructure has been developed as opposed to "how", and that the effectiveness of a civil engineering project will include judgement about its contribution to the community that it is serving (Owen *et al.*, 2011). There are however, specific aims of the learning experience that complement literature and theory as described below.

2.3.1 The Town Trail – learning from experience

Cotton and Winter (2010) discuss a number of sustainability pedagogies, noting that underlying many approaches is support for active, experiential learning and the use of the local environment for educational purposes. The Town Trail was run in each of the last four years, using the campus locale by asking students to undertake a 3 hour walking tour of Newcastle upon Tyne city centre, calling at various Points of Interest – the exercise could, of course, be run using any urban area. For Newcastle upon Tyne, the Points of Interest include public transport stations; St James' Park stadium; and the Tyne's bridges. In lectures building up to the Town Trail exercise, students have been presented with an introduction to the rise of human and societal considerations in civil engineering, Steels' conflicting parameters of civil engineering (2011), and an introduction to basic systems description (e.g. inputs, outputs, hierarchy) and analysis (e.g. stock & flow or input & output diagrams) based on Meadows (2008) and Dandy et al. (2008).

A table listing each Point of Interest against Steels' six conflicting parameters is given to each student to support field note taking. A set of questions is offered for each Point of Interest to try to stimulate and guide reflection by the student. For example, Newcastle upon Tyne's Central Station, the main national rail station for the city, has the following questions: "What role is this station fulfilling in terms of the transport need? Is it an interchange between transport methods? Is it local, national or international travel? Are people more likely to use it for business or leisure travel? Why do you think this?"

2.3.2 Sustainable Community Priorities – practice-based learning

In the second exercise, which has run in each of the last two years, a lecture format was used to present and define the seven components of sustainable communities from The Egan Review (Office of the Deputy Prime Minister, 2004). Students were then given time to discuss and debate the rank order of importance of each component from two different points of view: as a civil engineer; and as a citizen of the community. This exercise took place in a large classroom with students working in allocated groups that were designed to mix gender, nationality, course and age.

2.3.3 Earth 2.0 – engineering by doing

In this seminar exercise, first delivered in the 2012-13 academic year, ten groups, normally of nine students per group, were led through a discussion around a systems approach to engineering and the impact of civil engineering infrastructure development. Each participant was asked to arrive at the session having identified a civil engineering achievement or project that they felt epitomised civil engineering, and/or was a major success – no more guidance was offered so as to avoid steering the students' choice. Each student briefly presented their chosen project before the seminar's leader, a staff member, chose one project to focus on, and led the group through a debate around the positive and negative aspects of the project. Having identified that any project will have positive and negative impacts, the groups were challenged to identify infrastructure that, should civilisation have the opportunity to "start again" on a new Earth-like planet ("Earth 2.0"), they would forego so as to avoid its negative impacts. Having debated which infrastructure developments and achievements society could forego, the groups were challenged to try and identify what would the "Enablers of Success" (de Weck *et al.,* 2011) be in realising civil engineering infrastructure in the future that we would keep in a Earth 2.0 scenario.

2.4 Summary of the concepts behind the exercises

Table 1: Summary of First Year Student Experience and Civil Engineering concepts by exercise

			Town Trail	Sustainable Community Priorities	Earth 2.0
First Year Student Experience	Tudor *et al*. (2010)	Institutional Characteristics	✓		✓
		Group Work	✓	✓	✓
		Assessment & Feedback	✓		✓ *feedback*
	Willis (2008)	1st semester practical experience	✓	✓	✓
		Group Work	✓	✓	✓
	Bovill *et al.* (2011)	Graduate Abilities	✓	✓	
		Engaging Experience	✓	✓	✓
Civil Eng.	Steels (2011)	6 conflicting parameters	✓	✓	✓
	Multiple Authors	Systems Approach	✓		✓

3 Results

Capturing student feedback for the exercises and the experiences has been difficult owing to the three exercises falling in to two different study modules: the Town Trail and the Earth 2.0 seminar in one, and the Sustainable Communities exercise in another. Whilst acknowledging these limitations, some comments relating to the exercises have been recovered from feedback that is available for the module in which the Town Trail and Earth 2.0 seminar were delivered. Student assessment of the module is shown in Table 2.

Table 2: Feedback results for study module containing the Town Trail and Earth 2.0 exercises

	Strongly Disagree 1	2	3	4	Strongly Agree 5
The module was well structured	4%	7%	22%	37%	30%
The content was intellectually stimulating	0%	4%	30%	37%	30%
Overall, I am satisfied with this module	0%	0%	26%	48%	26%

In response to the question "What are the best features of this module?" responses included:

"Introduces us to the wider challenges facing civil engineers. Comes at us from a different angle, not the technical side of the degree. Sustainability issues well delivered and the comparison between

factors important to the engineers and factors important to the community was interesting. I thought the Earth-2.0 seminar worked very well."

"The content is something a bit different to the other modules, and really opens your mind to alternative viewpoints on civil engineering projects. I found it intriguing and very rewarding."

"It provides with students [sic] a broad understanding of combined issues prior to the commencement of an engineering project, particularly involved in the governance, human consumption and so on."

"The variation of teaching methods"

"*The smaller group work and the level of interaction it allowed us to have with the lecturer on topics*"

Results and observations for each exercise follow.

3.1 Town Trail – learning from experience

The Town Trail is written up by each student as a piece of reflective writing. The modal form of writing was descriptive writing as defined by Hatton and Smith (see Moon, 2004, p.97): "a description of events. The possibility of alternative viewpoints is accepted but most reflection is from one perspective." Examples from student submissions demonstrate some success for the Town Trail exercise in encouraging students to view infrastructure analytically, and support their first year experience:

"Although I have not seen anything new on the Town Trail, I have looked at a certain places in a new way."

"Whilst a large, chunky bridge such as the Tyne Bridge made of steel and concrete is obviously going to have an effect on the environment, I feel the grandness and iconic appearance adds to the visual environment."

"…it is clear that the city is not just a simple system. It has a complex network of inputs and outputs, all of which interconnect to form a hub of social, environmental and economic activities."

"I found the town trail very interesting as I … had not been to Newcastle prior to my arrival for University, so this gave me a chance to walk around … and appreciate the city itself as well as the civil engineering"

Reidsema and Mort (2009) acknowledge the contrasting nature of assessing reflective writing to "hard"/numerical evidence of student learning and the perception of the marking process being tedious, particularly where there is a large class managed by a single academic. The lead author found the marking of the Town Trail to be time-consuming but, owing to the range of observations, depths of reflections, and breadth of review, the marking was not tedious.

3.2 Sustainable Community Priorities – practice-based learning

In the first delivery of this exercise (2011-12), each group was asked to rank Egan's seven components of a Sustainable Community in order of importance, from two different perspectives: a civil engineer and a community member. One pair of ranks was returned for each of the 14 groups. The rank orders of importance were found to be reversed (ρ = -0.64) but, as this was based on a relatively small sample size and that a group response may not fairly reflect the breadth of views held by the student body, the exercise was undertaken a second time in 2012-13. This second delivery of the exercise still asked students to discuss and debate the components as a group but collected responses from students

individually (n = 72; 55 male, 52 female; 57 UK, 1 EU, 14 International). The average rank for each component was calculated and is presented in Figure 1.

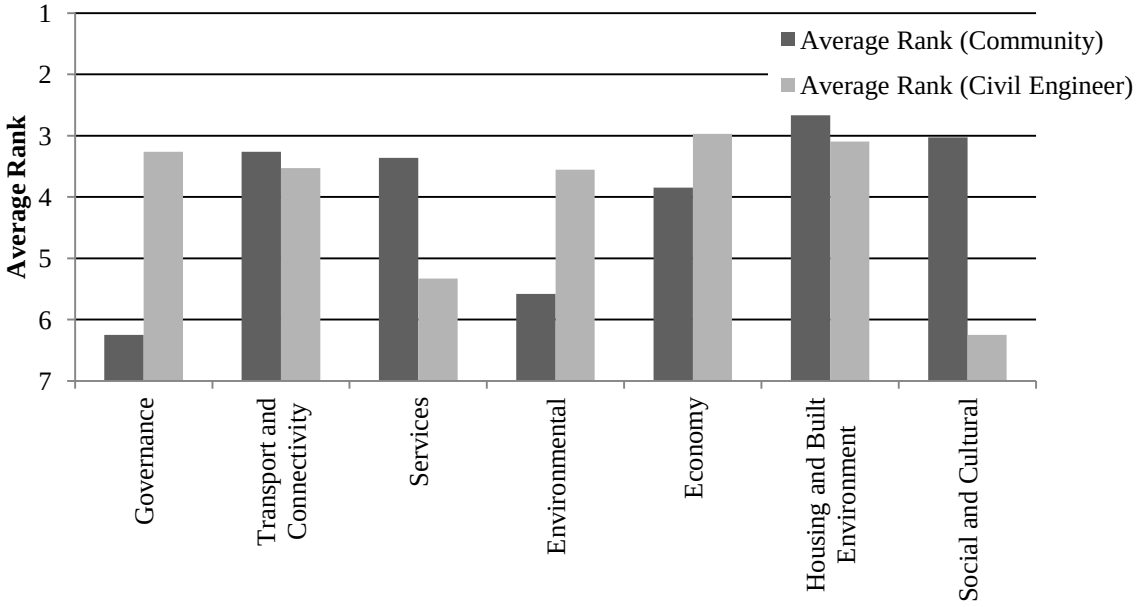

Figure 1: Students' rank average of Egan components of a sustainable community from their perspective as a civil engineer and a community member.

There are a number of interesting aspects to the data. The rank orders are reversed in this larger sample size (ρ = -0.14) but no one component stands out as of significantly greater rank importance than any other in its series. By contrast, some components stand out owing to their lower ranking: Social & Cultural from a civil engineering perspective; and Governance from a community perspective. It is the difference between average rank for the two different perspectives that are of greatest interest as this shows where students are likely to experience the conflict and challenge the civil engineers' face. The differences in average rank of 3.2 for Social and Cultural, and 3.0 for Governance are the greatest. The authors were surprised, however, that Governance was ranked more highly from a Civil Engineering perspective than the Community perspective.

3.3 Earth 2.0 – engineering by doing

In presenting and discussing different infrastructure achievements from around the world, each seminar group demonstrated an understanding of cost:benefit trade-offs and compounded impacts of infrastructure development. For example when discussing the Panama Canal, one individual spoke of its significant local environmental impact but global economic importance. When discussing the Hoover Dam, one group identified seven positive and seven negative aspects of the project. Interestingly, one negative that was proposed was that the hydropower scheme "wasn't built big enough", alluding to the need to future proof when developing infrastructure.

No group succeeded in unanimously agreeing on some aspect of infrastructure they would not develop again although there were clusters of consensus for change were society to have the chance (e.g. a need for different approaches to power generation). When asked why identifying infrastructure that we would forego on Earth 2.0 was difficult, example responses from students included, "everything has a knock on effect" and "you can't please everybody" which students recognised as relating to impacts. By contrast, however, they also acknowledged that infrastructure development was being driven by societal demand.

The Earth 2.0 seminar was well received by many in the student body. Through both formal and informal channels, many students asked for more small group seminar teaching to be used in future.

4 Future work

The three exercises could all be updated or adjusted in some way. The Town Trail exercise has the potential to be moved to a digital medium. Something similar has been trialled at the University of Edinburgh as part of their Innovative Learning Week (unpublished). The Egan exercise, whilst valuable, is perhaps now rather dated owing to the age of the review so more contemporary definitions and descriptions of sustainable communities should be sought but the challenge of ranking components from different perspectives should be retained. Anecdotal and recorded student feedback has suggested that more small-group debates, like the Earth 2.0 seminar, be held as part of student work around sustainable civil engineering systems. Whilst these debates are interesting and enjoyable to experience as staff, they require a ratio of approximately 15 hours of preparation and delivery to 1 hour of experience for each student. Greater continuity for the students through the exercises could be achieved by them completing each exercise in the same group of peers.

Each exercise could be explored in more depth to form individual analyses using both qualitative and quantitative analysis. This could be done over a period of years to measure changes in students' perception and understanding of civil engineering complexity. For example, exploring the Town Trail reflective writing in more depth, collecting more student feedback on the Earth 2.0 exercise, and adding in some level of benchmark/control at the start of the academic year to the ranking exercise, would all afford greater analysis of the students' perceptions.

Exploring patterns and trends with other University cohorts would be an additional and welcome development.

5 Conclusions

The need for engineers to embrace concepts and expertise outside their technical discipline has been, and continues to be, discussed and accepted by many involved in the profession. The role of, and need for, higher education to create and promote a holistic approach to engineering is a key part of developing sustainability literacy amongst future engineers.

This paper has presented three first year undergraduate civil engineering exercises designed to explore the complexity and conflicting parameters in civil engineering including concepts from outside the traditional domain of engineering e.g. social & cultural, and governance factors.

The three exercises seem to succeed in contributing towards future engineers having a broader understanding of engineering success, improving engineering decision making, and doing so through alternative pedagogies. They also support the first year student experience as indicated in score-based, qualitative and anecdotal feedback. It is hope that the exercises and experiences presented in this paper can be utilised by other civil engineering degree providers.

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