

SUSTAINABILITY: WORDS OR DO WE REALLY TEACH THE ENGINEERS EFFECTIVELY?

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Abstract: Sustainability is an important concept of engineering education and methods of embedding it into curriculum are continuously sought. The Institution of Chemical Engineers 'sees sustainable development as the most significant issue facing society today' (IChemE) and places great emphasis upon the embedded learning of sustainability within the curriculum, as evidenced in their new accreditation guidelines. Newcastle University was amongst the first to gain funding from RAE for a Visiting Professor in Principles of Design for a Sustainable Environment. This led to the development of a number of case studies used in the education of engineers.

This contribution describes the efforts at CEAM to embed sustainability into curriculum from week 1 of chemical engineering curriculum. These include a week long module of introduction to chemical engineering in the first year, a number of industrially relevant case studies within Enquiry Based Learning (EBL) that have a great societal impact. Details of the transition towards EBL, the case studies on fuel cell effectiveness and sustainable plant design are provided. Emphasis is placed on the methods of assessment of student learning as well as methods of evaluating the effectiveness of delivery using case study approach. Student focus groups and diamond ranking confirmed that students perceive the case studies as very important and prefer developing their skills of sustainable design in realistic setting.

Keywords; sustainability in chemical engineering curriculum, Enquiry Based Learning, assessment.

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1. INTRODUCTION

1.1 Sustainability in higher education

Limited resources on Earth and the resulting economic, social and environmental challenges facing society are prompting extensive debates about the role of higher education in developing appropriate attitudes of students towards these issues. The Department for Innovation, Universities and Skills (DIUS) identified sustainable development as an important part of HE:

“Sustainable development – meeting the needs of the present without compromising the ability of future generations to meet their own needs – is a defining challenge of the twenty-first century. If the nation is to play its full part in challenging global poverty and combating environmental problems like climate change it is imperative that everyone in this country develops the skills of sustainable living and working. That means placing sustainable development at the heart of skills provision, ensuring that it is a fundamental goal of our economic and social progress.” (DIUS 2007, section 1.20)

Professional institutions, such as the Royal Academy of Engineering and the Institution of Chemical Engineers, have introduced a number of initiatives to encourage the integration of sustainability into HE as well as its industrial application. This is evidenced, for example, by the requirement placed on the academic institutions seeking accreditation of their courses by IChemE to demonstrate sufficient provision of embedded teaching of SHE, sustainability and ethics (IChemE, 2009) or by the provision of a sustainability metrics tool to help industry assess the impact of their operations (IChemE) and the provision of guiding principles on engineering for sustainable development (RAE, 2005).

1.2 Chemical engineering curriculum at Newcastle University

Nationally chemical engineering curriculum has traditionally been delivered in a relatively conservative manner. The changes in the world-wide market as well as societal challenges we are facing require a review of not only the content, but also the mode of delivery of the fundamental knowledge and skills in this area. Curriculum review process was initialised at CEAM, Newcastle University in 2007 and involved detailed research into effective methods of engineering curriculum delivery enabling the development of employability skills – problem solving, team working, data analysis, etc. Whilst the School benefits from the University Graduate Skills initiative, providing students’ opportunity to develop ‘transferable skills’, feedback from potential employers stressed the importance of developing critical skills in subject context.

The requirement for the Universities to ensure that ‘they are preparing their students for today’s competitive job market’ is widely recognised (e.g. Knight and Yorke, 2003), but so is the difficulty of achieving this in academic environment (Cranmer, 2006), in particular at the current, very challenging economic climate (Rae, 2008). Emphasis on testing at earlier stages of education led to the ‘loss’ of important employability skills and thus CEAM decided to strengthen this aspect in their ongoing curriculum review. Enquiry based learning, centred on students working in small groups and solving of industrially relevant problems provides an opportunity to reinforce the subject knowledge and develop important skills.

1.3 Progressive development of sustainability theme through the curriculum

Students are introduced to the concept of Sustainability by a Royal Academy of Engineering Visiting Professor in Principles of Design for a Sustainable Environment. This occurs in their first week in the School. The one week special programme introduces students to the fundamentals of chemical engineering and allows them to consider the necessity of covering particular subject areas of chemical engineering within the curriculum, based on a realistic, but simple design problem. The students are presented with the design problem and specific tasks to be addressed on the first day of teaching. Subsequent contact sessions provide the necessary background knowledge in mass and energy balances, fluid flow, heat transfer and sustainability

in order to solve the tasks. Students work in groups of 5-7 and have a number of tutorial sessions timetabled during the first week, when academics provide 'consultation' to the groups on various aspects, as required. Two weeks later, students present their solutions to academic staff in a 30 min interview session (Figure 1).



Figure 1 Small group presentation of the design task wet in week 1 in Stage 1.

A more detailed introduction to sustainability topics, such as global warming, ozone depletion, toxic emissions, poor air quality, water shortages and water pollution, acid rain, persistent organic pollutants, depletion of natural resources, loss of biodiversity, contaminated land, ecological principles, natural cycles, eco and carbon footprinting is provided within a compulsory module on Principles of Chemical Engineering. This module also introduces the role of an engineer in sustainable development, the issues of responsible care as well as issues of risk, liability and corporate manslaughter from the legal perspective. The relevant legislation framework and fundamentals of inherent process safety, COSHH and COMAH regulations, consequence of unsafe design and an examination of the issues surrounding the balance of cost and safety are covered in this module.

In 2009 a new case study on alternative energy sources was introduced to encourage students to use fundamental scientific principles acquired during chemistry and thermodynamics lectures to understand the working principles of both batteries and fuel cells and to be able to make calculations of cell voltages and cell efficiencies. The task, 'Fuelling a manned mission to Mars', inspires students to investigate effective energy sources (for example direct methanol, molten carbonate, phosphoric acid, alkaline and proton exchange fuel cells) and work in teams to devise the most efficient solution. Students have a series of timetabled group work sessions, including laboratory practicals, during which they can investigate the efficiency of certain types of fuel cells. The outcome of this case study is a group oral presentation and a group report. Peer marking is also used to achieve fair distribution of marks.

In Stage 2 the topic of responsibility and regulations is further developed in the Safety and Engineering Practice module. This module deals with SEVESO I and II Directives, risk management and environment, REACH, codes of practice and environmental law, risk hierarchy

(i.e. eliminate, substitute, contain, protect workforce), emergency planning, protective equipment, training and management issues. In a workshop setting students are encouraged to think about risk and risk communication. This is based around a typical chemical plant and students evaluate the potential risks, who the stakeholders are, what they would need to be told and how to communicate effectively. Video footage and case studies of previous key industrial safety incidents illustrate Safety, Health and Environment & Loss Prevention principles. Risk and safety tools, including Hazard Operability (HAZOP), Hazard Analysis (HAZAN), As Low As Reasonably Practical (ALARP), Fatal Accident Rates (FAR) and Fault tree analysis provide the students with necessary technical knowledge for assessment of the impact of the planned operation. In addition SHE and sustainability topics are addressed in the subject specific modules, where these issues are emphasised in design approaches for unit operations, such as separation and reactor design.

In Stage 3 students are exposed to examples of clean technology research and its applications across a breadth of areas of chemical and materials engineering. The idea is to highlight the range of applications and sustainability of the concepts, (i.e. consider social, economic and environmental aspects), approaches and barriers to the implementation of clean technologies. The sustainability learning outcomes are brought together in the major group design project. Here the three components of sustainability - environmental responsibility, economic return and social development – represent an integral part of the design of the plant to satisfy given specifications. A significant proportion of the assessment of the design project is dedicated to these issues and students are required to critically address them. The final presentation of the design solution to the industrial panel specifically includes the assessment of sustainability of the design and the panel members include the RAE Visiting Professor in Principles of Design for a Sustainable Environment and practicing engineers with sustainability responsibility within their companies. The presentations are usually highly praised by the panel and indicate a high level of knowledge and skills in this area that the students gained over the three years of their studies.

In Stage 4 (MEng programme) the sustainability theme is further developed in the Enhanced design module and a range of optional modules specialising in Sustainable processing, energy and materials technology, Sustainable design and manufacture or Sustainable industry. These modules also build upon and utilise material produced from the RAE programme and include concepts such as Carbon footprinting, Life Cycle Assessment, Product Stewardship and Producer Responsibility delivered in a highly participative way. For example, students are divided into groups and they are asked to prepare and LCA for a given project, for example assessing a proposed onshore wind farm (MiddleMoor near Alnwick) or assessing a proposed gasifier to treat municipal solid waste in Newcastle upon Tyne. Half of the group is using the LCA approach to justify the case FOR and the other half AGAINST. The evidence and conclusions are presented in a group oral presentation together with social and economic issues. Students are encouraged to make key assumptions concerning life expectancy, location, sourcing of materials, data source and quality, recycling etc. If the LCA initiation stage is excessively skewed to suit the ‘for / against’ purpose, it would be thrown out by a peer review panel.

2. METHODOLOGY

2.1. Focus groups

Two focus group sessions have been organised. The first group consisted of 14 Stage 3 and Stage 4 students working in pairs and used diamond ranking (Woolner et al. 2010) to answer the following question:

1) What modes of delivery promote deep learning and professional skill development?

The outcomes of the diamond ranking were used as a basic structure for the following semi-structured interviews with 16 Stage 3 and Stage 4 students. In addition the results of an industrial focus group organised at an earlier stage, consisting of 9 representatives of potential employers, were used as discussion points to compare the views of students and those of employers.

The second focus group consisted of 9 Stage 1 students currently undertaking the EBL curriculum. These students participated in a semi-structured interview during which their views on the effectiveness of case study based EBL curriculum were sought. The focus group was facilitated by a researcher external to the school and in complete anonymity, to encourage students to express their views without reservations. The transcript of the session was then provided to the author and is discussed in the results section.

2.2 ELLI questionnaire

The Effective Lifelong Learning Inventory (ELLI) was developed at the University of Bristol, in a project funded by the Lifelong Learning Foundation (Deakin Crick and Yu, 2008). In ELLI seven dimensions of learning power are defined as:

- *changing and learning* (C&L) - a sense of oneself as someone who learns and changes over time; the opposite is being 'stuck and static'
- *critical curiosity* (CC) – an orientation to want to 'get beneath the surface'; the opposite is being 'passive'
- *meaning making* (MM) – making connections and seeing that learning 'matters to me'; the opposite is simply 'accumulating data'
- *creativity* (CT)– risk-taking, playfulness, imagination and intuition; the opposite is being 'rule-bound'
- *resilience* (RS) – the orientation to persevere in the development of one's own learning power and relish challenge; the opposite is being 'fragile and dependent'
- *strategic awareness* (SA) – being aware of one's thoughts, feelings and actions as a learner and able to use that awareness to plan and manage learning processes; the opposite is being 'robotic'
- *learning relationships* (LR), or interdependence – learning with and from others and also being able to learn alone; the opposite is either being 'isolated' or 'over-dependent'

This method has been used in establishing links between the disposition of students to learn and the change in the mode of curriculum delivery towards Enquiry Based Learning. The new enquiry based curriculum delivery was implemented from September 2009 in Stage 1. ELLI questionnaire was administered to 72 Stage 1 students, following this method of delivery and 47 Stage 2 students, who completed Stage 1 curriculum without the benefit of the case study based EBL. The initial analysis of learning power provides a base value before and after intervention for Stage 1 and comparative values for the 'control' Stage 2 group. The ELLI questionnaire will be administered to the same students again in May 2010 to provide a comparison reflecting the

impact of the EBL. The ELLI scores will also be compared to the academic performance of students to note any correlations. This analysis will only be possible at the end of the academic year.

3. RESULTS AND DISCUSSION

3.1. Focus groups

Students in the first focus group felt that practical skills and relevant subject knowledge were most important in promoting deep learning and professional skill development (Fig 2 with very detailed comments). It is thus not surprising that they almost unanimously identified industrial case studies solved in small groups, linking several modules and labs together, as the most effective method of achieving this and placed large lectures with lots of information delivered at the bottom of the diamond. Whilst the current delivery is in fact almost the opposite, the students themselves identify the need to practice professional skills hands-on with real life problems. This opinion was also voiced by the industrial focus group and clearly supports the move towards EBL case study based delivery.

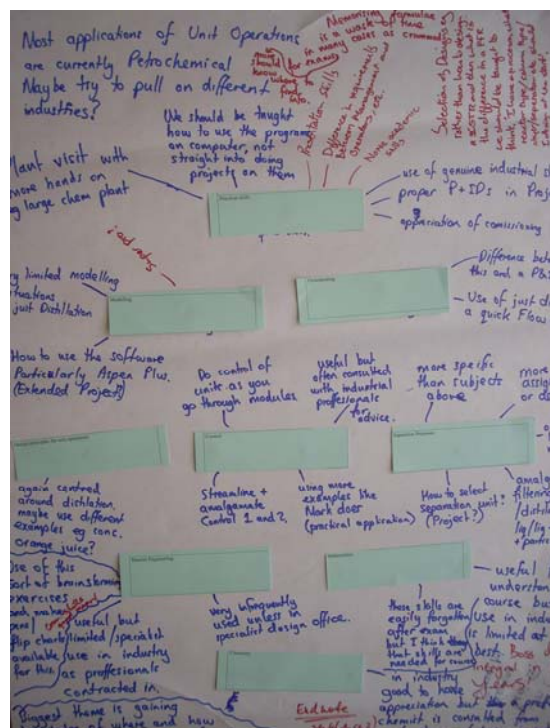


Figure 2 Diamond ranking representing students views of chemical engineering curriculum and its effective delivery

Interestingly, the students commented on subject areas they would like to see strengthened in the chemical engineering curriculum and amongst areas mentioned was deeper technical knowledge of alternative energy source, including nuclear energy. This demonstrates the high level of sustainability awareness of students.

Stage 1 students commented generally positively on the case studies during their focus group. One student said that it was ‘quite good to apply what we have learned to the actual real world and industry but some of them are quite hard, throws you in at the deep end.... but I guess that is the point.’ Generally the participants of this focus group found working in groups to be a positive experience. The negative aspects which were commented upon by many of this group were that there could be an element of unfairness if some members of the group did not participate fully. This is a common concern amongst students of all stages and the School addresses this issue in a number of ways, including peer assessment of individual contribution of each group member or using individual reflective reports to moderate the group mark attributed to each group member.

3.2 ELLI questionnaire

At this stage only the baseline results of ELLI questionnaire are available. The comparison will become available only after the questionnaire is administered to the students again in May 2010. Figure 3 summarises the mean responses of students in each category of learning power in Stage 1 (Figure 3a) and in Stage 2 (Figure 3b). The colour scheme represents the percentage ELLI scores in each category for a given percentage of students from each cohort.

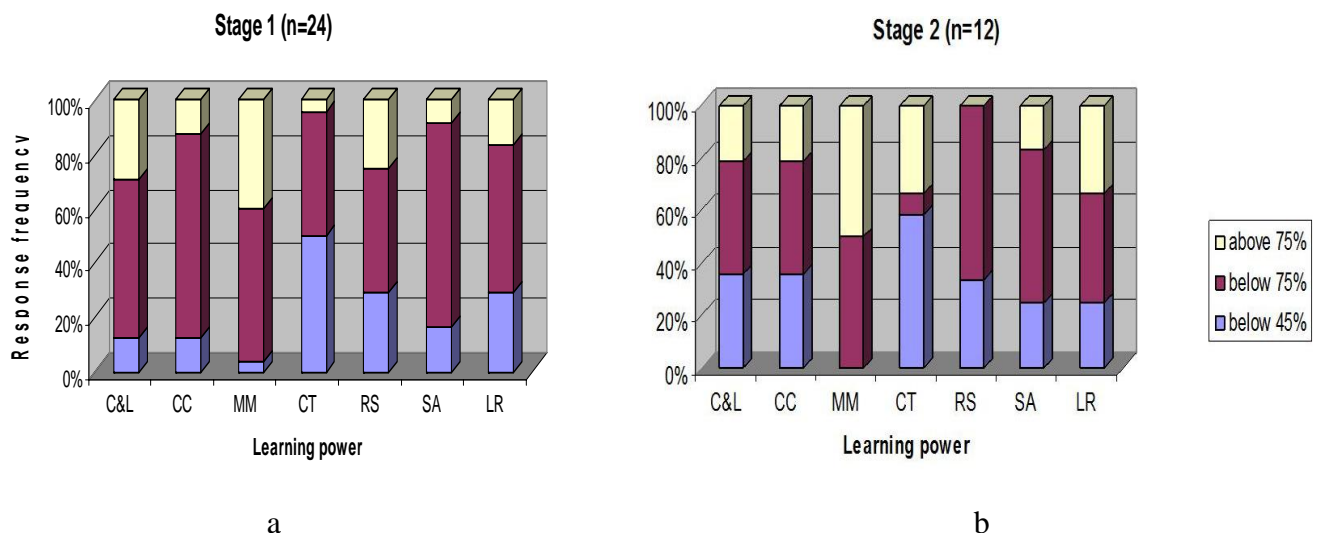


Figure 3 Mean ELLI scores in each category of learning power (described in detail in section 2.2) for Stage 1 (a) and Stage 2 (b) students.

Although the response rate was relatively low in the initial stages (33.3% for Stage 1 and 25.5% for Stage 2), these responses are providing an interesting comparison of the learning power of this sample of each cohort. The most marked differences between the two cohorts are in meaning making (MM), creativity (CT) and resilience (RS). Interestingly the resilience of students in Stage 2 seems to be lower than those in Stage 1. Whilst somewhat surprising, as students in Stage 2 has been ‘challenged’ with engineering problems for a longer period than Stage 1, the introduction of highly subject specific and detailed topics in Stage 2 may influence the dependence of students in this stage upon the academics in achieving their learning goals. This also may explain the higher mean scores of Stage 2 students in the other two categories. It will

be interesting to see if the case studies and EBL will increase the mean scores of Stage 1 students in these two categories by the end of the academic year.

4. FUTURE PLANS

Student focus groups provided valuable material for the continuing curriculum review process taking place at CEAM. Curriculum for Stages 3 and 4 is currently being revised with input from students, but also industrial focus groups and professional and quality assuring bodies. Full ELLI analysis of the first two cohorts of students will be available by the end of June 2010, although the intentions are to use this methodology for future investigations to gain understanding of long term impact of EBL upon student learning together with the assessment of sustainability attitudes of students.

5. ACKNOWLEDGEMENT

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