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Instructional Strategies to Educate for Sustainability in Technology Assessment*

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There have been widespread calls for the types of action that will create a sustainable society. As a response, sustainable development criteria have been incorporated into undergraduate engineering accreditation requirements. Engineering education is also responding, with sustainable development knowledge and skills being increasingly integrated into the curriculum at both a course and subject level. However, there has been less focus on the type of instructional strategies needed to achieve these learning outcomes. A focus on learning strategies is necessary to create the integrated and interdisciplinary perspective required for sustainability education. Active learning strategies, which use methods that can accommodate conceptually and practically diverse data and divergent epistemologies are needed. Roleplay-simulation, online debates and scenario building are active, participatory instructional strategies. These methods were applied in a subject about Technology Assessment within the context of exploring issues about science, technology and society. These methods were found to be effective for developing and demonstrating understandings about the multiple dimensions (e.g. social, technical, environmental, economic, political) of complex engineering activities. These active and participatory learning methods have a clear place in the engineering curriculum if the transformation in thinking, values and actions required for a move towards sustainability is to be achieved.

Keywords: simulation; sustainable development; e-learning; water; computer mediated communication

INTRODUCTION

SUSTAINABILITY is now widely recognized as an issue that needs to be addressed within both engineering practice and engineering education. Sustainable development can be described as simultaneous progression of our economic, social and environmental goals. Within education, measures have been taken to incorporate sustainable development criteria into both engineering accreditation requirements and the curriculum. In Australia, a National Review of Engineering Education [1] identified generic attributes, which were to form part of the basis of the accreditation of undergraduate engineering degrees. These include:

- Understanding the social, cultural, global and environmental responsibilities of the professional engineer, and the need for sustainable development;
- Understanding the principles of sustainable design and development.

In the United States, accreditation outcomes required by ABET (Accreditation Board for Engineering and Technology) address aspects of sustainability. One outcome is that students should have 'the broad education to understand the impact of engineering solutions in a global and societal context' [2]. The impacts are defined to include political, economic, religious, environmental, communication and aesthetic considerations. They also identify as an outcome the need for knowledge of contemporary issues.

These curriculum reforms, it is hoped will allow the development of engineers who can participate in the process of moving society towards sustainability. To develop this sustainable future their efforts 'must consider the interplay and dynamic evolution of social, economic, and natural systems, thus requiring an integrated and interdisciplinary perspective. They must go beyond specific themes and sectors- population, economy, water, food, energy, climate-to analyze interconnections, common drivers, and system wide changes. They must understand the process of securing sustainability as tentative, open and iterative, and involving scientific, policy and public participation' [3]. Clearly the implications of incorporating sustainability concepts and methodologies into our educational curriculum and the creation of professionals able to rise to this challenge are enormous.

The need for an integrated and interdisciplinary perspective on issues often emerges within the many definitions and approaches found in the literature about educating for sustainability. How disciplinary differences and perspectives are handled within the curriculum is therefore important. A discipline can be considered as 'training that corrects, moulds, or perfects the mental facul-

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ties or moral character' [4] or alternately 'the study, or practice, of a subject using a specific set of methods, terms and approaches' [5]. These encompassing views of disciplines suggest that disciplines can be considered as structures of not just knowledge but also a culture [6]. However an integrated perspective requires the integration of knowledge derived from various disciplines. It is therefore the degree of integration during an investigation into a specific issue or problem, which characterizes the various approaches to disciplinarity. Interdisciplinarity can be equated with the integration of disciplines and sub-disciplines while multidisciplinarity is their juxtaposition but not their integration [7]. However, it has also been argued that it is not helpful to think of sustainable development as cross or trans or multi-disciplinary because it prompts the question of which disciplines are being crossed and which are included or excluded [8].

Bringing the disciplines and the diverse knowledge and values they contain together to solve a problem in the engineering classroom can be problematic. Challenges arise because of differences in disciplinary epistemologies, discourses and traditions in teaching and learning along with differences in students' preferred learning approaches and styles. Some learning styles are more adaptive to some disciplinary knowledge structures than others [6]. How these challenges are dealt with determines the extent to which sustainability development criteria are integrated into the curriculum.

It is widely advocated that sustainability be integrated into the content and delivery of all curricula [8]. At its most basic level, educational material, which has sustainability concepts embedded, can be integrated into the engineering curriculum. This material could include lectures and case studies followed by small group discussions. At a deeper and more integrated level, this could involve the creation of learning activities that can accommodate, conceptually and practically, both the diverse data and divergent epistemologies necessary to develop integrated and interdisciplinary perspectives in engineering students. It is important to realise that 'sustainable development is as much about values and ethics as it is about science and technology. Practical change in our ethics and values is absolutely necessary if sustainability is to be achieved—just as necessary as scientific and technological advance' [9]. Engineers therefore must have some capacity to use qualitative data which are necessary to describe critical dimensions of sustainability such as culture, values, lifestyles and social organization. This must be accommodated in addition to the use of quantitative data which is more familiar to engineers.

Active approaches to teaching and learning that involve a more discursive and collaborative attitude to problem-solving as well as those which seek to illustrate and accommodate value diversity are needed. The challenges that educators face in finding suitable teaching and learning methods also face engineering professionals when working on complex societal problems within the fields of Technology Assessment [10], Risk Assessment, Participatory Integrated Assessment [11], and Participatory Policy Analysis [12]. In these fields participatory approaches involving 'methods to structure group processes in which non-experts play an active role and articulate their knowledge, values and preferences for different goals' are used [13]. The methods used include Delphi, scenario building and analysis, gaming/simulation, participatory modelling, focus groups, citizen juries, consensus conferencing and participatory decision analysis. A central characteristic of these methods is that they combine elements of deliberation and representation. Deliberation can occur through an extended dialogue or discourse designed to generate shared values amongst participants. Multiple representations are needed since no single perspective can fully encompass the whole system or issue at hand. With the introduction of multiple perspectives there is a need to integrate different types of knowledge (e.g. non-technical, scientific). These participatory methods have considerable scope for adaptation to the educational domain. They meet many of the characteristics required of an active learning approach, which can develop sustainability knowledge, create integrated and interdisciplinary perspectives and provide students with exposure to techniques that are authentic in the practice of engineering.

TEACHING CONTEXT

Technology Assessment is a compulsory senior undergraduate engineering subject which has between 100–200 students and involves students from the Civil, Civil and Environmental, Computer Systems, Electrical, Mechanical, Software and Telecommunications Engineering disciplines.

As a field of study Technology Assessment has many different forms depending upon the context in which it is applied. It seeks to analyse technological developments and their consequences. When the subject started in 1998 it was built around a technical approach to technological policy decision-making where it was thought that better decisions would be made through better expert information input and impact studies. The subject curriculum has evolved along with the shifting views of policy-makers to a more political approach where it is believed improved public decisions will occur through improved socio-political processes including the use of open participative approaches. The problems addressed are often complex, multifaceted, ill-defined and fraught with value judgments.

Technology Assessment provides an overview of the different approaches to assessing technology both for informing public policy and for impact.

The process of policy making, the influence of participatory mechanisms and the nature of the problem to be managed are considered. It also examines the legal, political, economic, environmental and social frameworks that can be used to assess technology and its impacts. It considers how to evaluate the outcomes and impacts of large-scale complex engineering systems from a decision-maker's perspective.

There are three main assessment tasks that students in Technology Assessment undertook; Task 1 quiz (10%), Task 2 either the Structured Academic Controversy Forum or Mekong eSim or Scenario Building activity (30%) and the Task3 Technology Integration report (60%). The Task 1 online quiz focuses on student understanding of approaches to decision-making, technology assessment models, public participation strategies and the causes of conflict. The Task 3 Technology Integration report requires students in groups of four to design a scoping level study into the evaluation of a technology project, plan, policy or programme. The students select one of the available four report types and then identify their own topic which suits the type of report they are undertaking. For the Impact Evaluation report students design an impact evaluation study using qualitative and quantitative indicators of impact which links a technology with social and other impacts. For the Stakeholder Engagement report students design a stakeholder consultation strategy to be used as part of a Technology Assessment process. For the Product-service evaluation report students critically evaluate the ability of alternate product-service options to achieve a function and evaluate the economic, environmental and social consequences of alternate product-service options. For the Innovation Evaluation report students identify a specific product or service which can be created or improved and evaluate the economic, environmental, technological and social factors which need to be considered during the innovation evaluation process. The three activities which are available as alternates for Task 2 are the focus of this paper and described in the following sections of the paper.

ROLEPLAY-SIMULATION

Gaming and simulation can be described as a type of 'policy exercise' where heterogeneous participants explore policy options. Roleplaying within a simulation/gaming framework allows human participants to adopt a role that encompasses a set of interests, values and knowledge. These perspectives are then made operational within a simplified but functionally relevant version of a complex decision-making context. Compared with other methods of integrated assessment, simulation/gaming has advantages in the integration of scientific with strategic, behavioural and judgmental knowledge, and in exploring the implications of diverse preferences and values [14]. In addition to roleplay-simulations being used in professional practice for dealing with complex issues, they can also be effective when used in educational settings. They can be used to develop discipline-specific knowledge and skills as well as work and life skills such as teamwork, decision-making, leadership, communication and negotiation. Roleplay-simulation has been used in education about environmental decision-making [15, 16] and specifically in engineering education [17, 18, 19, 20].

Within Technology Assessment an online roleplay-simulation (Mekong e-Sim) was used to explore issues related to sustainable development within the Mekong region of SE Asia. A fuller description of the Mekong e-Sim is described elsewhere [21, 22] including a detailed description of the nature of student interaction [23]. The structure and evaluation of the e-Sim described in this paper refer to the Mekong e-Sim run between 2001 and 2002. Within the e-Sim, students engaged in debates and negotiations on issues about large-scale engineering infrastructure development proposals. The activity has involved 2nd and 3rd year geography and engineering students from several geographically distant universities. Four to six students shared responsibilities for developing and enacting the role of each persona or stakeholder in the e-Sim. Approximately one half the groups comprised a combination of students from different disciplines or institutions. A key design feature was to have a broad range of perspectives represented within the student cohort.

The Mekong e-Sim was constructed around four key stages:

1. *The Briefing stage (Stage 1)* involves participants becoming familiar with the e-Sim structure, geographical context, requirements and technology as well as developing an understanding about the responsibilities, views and strategies of their adopted persona identity.
2. *The Interaction stage (Stage 2)* comprises interactions (primarily email) between different personas in response to events that have occurred and the actions of other personas. This stage requires students to formulate and make operational their understanding of their persona.
3. *The Forum stage (Stage 3)* involved online public forums based around a simulated public inquiry. This stage requires students to publicly share their perspective and then debate the merits of their position. As they observe the behaviour of other stakeholders and the impact of various actions and decisions, students develop an understanding of the perspectives of other personas.
4. *In the Debriefing stage (Stage 4)* participants identify what they have learned as a consequence of participating in the e-Sim. It can focus on the tacit norms underlying a judgment, the strategies behind an action and the feelings associated with an event or the specific role a person is trying to fulfil

The specific learning objectives of the Mekong e-Sim during 2002 were for students to:

- Identify the political, social, economic and scientific dimensions to decision making in the context of natural resource management conflicts.
- Identify the responsibilities and appropriate responses for characters in the roleplay-simulation.
- Develop communication, research, critical thinking, negotiation and decision-making skills and an appreciation of cultural differences and approaches.
- Utilise Information Technology and Telecommunication skills.

The effectiveness of the Mekong e-Sim has been assessed using a multifaceted approach including student feedback and analysis of student performance on formal assessment tasks. The student survey was designed to assess student perceptions of the extent to which the e-sim had assisted them in achieving the stated learning objectives. The analysis of student responses reported in Table 1 was from a paper-based survey using a five point Likert scale with strongly disagree (1) through to strongly agree (5) with a 58% response rate.

These results show strong student support for statements about the effectiveness of the e-Sim in meeting the learning objectives for the activity through awareness of the multiple dimensions to decision-making (item 12), knowledge about organizations in the region (item 13) and values awareness (item 15).

Evaluation of the extent to which the intended learning outcomes were met was based upon the extent to which higher order learning was demonstrated in the debriefing essays submitted by students. These debriefing essays were analysed using the principles of the SOLO taxonomy [24]. This describes five structural levels of learning outcomes ranging from incompetence to expertise based on the structural complexity of responses. The highest levels of response include outcomes that demonstrate integration of ideas and identification of an overall structure, followed by application of the understanding to new contexts. Since the learning aims of the Mekong e-Sim related to students' developing understanding of complex relationships and applying knowledge to other contexts this was considered an appropriate framework for assessment. Analysis of student performance indicated that 75% of the cohort had produced responses at the level of multi-structural and above. This suggests that the learning design of Mekong e-Sim supports student learning about multiple perspectives on problems and encourages transfer of learning to new contexts.

The e-Sim was also effective for raising student awareness about the influence of their value system on their behaviour during the activity. One student commented: 'It was especially hard to break through [your] own cultural conceptions and adopt a role of someone that [sic] lives in an entirely different situation with respect to livelihood, education, health, religious and cultural values'. A typical comment was: 'In some ways I was not successful in my attempt to keep them [my own and my persona view] separate, which surprised me, as I had assumed that I would be able to maintain dual views'. The roleplay dimension of the e-Sim was important in creating this value awareness within students.

Students identified the different skills that participants from different discipline areas brought to the activity: ' . . . the members who were engineers were very good at looking at issues from a technical standpoint. Vice versa, the . . . geography majors were very good at looking at issues from a political, social, and environmental point of view'. ' . . . the engineers would see an event or issue differently than the two geographers would'. Students appreciated the different expertise that they and others brought to the scenario, and acknowledged that the e-Sim created an environment where students from different disciplines could work on the same problem contributing different knowledge, skills and opinions.

STRUCTURED ACADEMIC CONTROVERSY FORUM

Structured Academic Controversy (SAC) is an instructional technique which seeks to create engaged co-operative learning through arousing intellectual conflict [25]. Students engage in the controversy by arguing a point of view, then swapping perspectives and finally coming to a reasoned judgment on the issue. Through this process students transform knowledge into argu-

Table 1: Student Response from Mekong e-Sim (2002 cohort)

Item No.	Survey Item	Mean
5	The e-Sim sharpened my analytical skills	3.3
9	The e-Sim developed my ability to seek and utilise knowledge from a range of sources	3.6
12	The e-Sim developed my awareness of the political, social, economic and scientific dimensions of natural resource decision-making in the Mekong	4.4
13	The e-Sim developed my knowledge of organisations involved in development of the Mekong Region	4.3
15	The e-Sim developed my awareness of the values and attitudes of other personae (roles)	3.8
	Number of Responses (n)	75

Table 2: Student response from SAC Forum (2003 cohort)

Item No	Survey Item	Mean
2	The online forum developed my ability to see a science and technological issues from multiple perspectives	3.6
3	The online forum developed my ability to seek and utilise knowledge from a range of sources	3.5
4	Task 2 developed my awareness of the political, social, environmental, economic and scientific dimensions of the issue discussed	3.9
6	The online forum and debriefing developed my critical thinking skills	3.6
	Number of Responses (n)	101

ments, critically analyse positions, view issues from different perspectives and synthesize [26]. It has been widely applied including in environmental studies [27], education [28] and Science methods classes [29]. It is particularly suited to a constructivist approach to learning where it is believed that individuals construct their conceptions of issues according to the way they focus on structure and integrate particular aspects of knowledge, attitudes/values and behavioural orientation.

The Structured Academic Controversy (SAC) technique has traditionally been used in face to face situations where there are two opposing points of view. However, many controversies which involve engineering and technology are multi-faceted and have many stakeholders. To satisfy these needs the Structured Academic Controversy technique was modified for multi-party controversies and for use with internet mediated communication. A fuller description and evaluation of the SAC Forum is provided elsewhere [30].

The learning objectives for the SAC Forum are to:

- Promote multiple perspective taking on a controversial science and technology public issue;
- Develop conflict management skills, critical thinking and collaborative skills.

The issues explored within the SAC Forum have focused on controversial public issues related to science and technology. These have included genetically modified foods, the provision of telecommunication infrastructure to meet regional needs, privatization of telecommunication providers, the role of e-libraries and the damming of international rivers.

Each of the SAC Forums comprises between 30–50 students who represented 10–14 personas (stakeholders), each of which comprise 3–4 students. The Forums are structured around three stages:

1. *Position Preparation (Stage 1):* Students research their assigned persona (stakeholder) and the issue defined by specific terms of reference for the forum. Each persona must post an initial statement describing the responsibilities, general viewpoints and/or value statements of the persona they are representing.
2. *Advocating Positions (Stage 2):* Students post messages to a threaded discussion board which relate to the persona's perspective or position on an issue as well as responses to the postings of other personas. A threaded discussion results from these postings as students attempt to persuade other personas of their views and positions.
3. *Debriefing and Reflection (Stage 3):* During this stage participants undertake both verbal and written critical reflection to recognize what they have learned as a consequence of participating in the activity. In their report they are required to present arguments which both support and refute those made by their persona. This stage requires the students to step outside the position they had in the forum and consider other perspectives.

The effectiveness of the SAC Forum has been assessed using student response to a paper-based survey and written responses during formal assessment tasks [30]. In the survey, all items used a 5-point Likert scale ranging from strongly disagree (1) through disagree, neutral, agree to strongly agree (5) and there was a 73% response rate (Table 2).

These results show strong student support for the effectiveness of the SAC in meeting the learning objectives for the activity through developing multiple perspectives (item 2, 4) and critical thinking skills (item 6).

SCENARIO BUILDING

Scenario building/analysis can be described as 'an interactive process of engaging a group in a process of identifying key issues, creating and exploring scenarios in order to learn more about the external environment and/or integrating the insights into the decision-making of the organization' [12]. Many different approaches to scenario building/analysis have been developed to suit the diverse contexts in which they are used. They all provide a systematic and structured way to incorporate and represent multiple causes and relationships into a narrative framework. The scenarios produced allow interdisciplinary and integrated perspectives to be represented.

A scenario building activity was used within Technology Assessment. The technique used was adapted from technology foresight exercises. A key objective was that students would create technological scenarios based around specific issues, which were both integrated and consistent with stated social and biophysical profiles given for the particular countries that the technologies would impact. The topics used have included educational technology, telecommunications infrastructure, transport (private, public, freight), water (supply, power, irrigation), space engineering, waste management, e-commerce, manufacturing, government information systems (e.g. tax, police, medical records) and energy (hydroelectric, solar, fossil, nuclear). The social and biophysical profiles for the countries included qualitative and quantitative information on the type of government, literacy, nature of the workforce and industries, electronic information infrastructure, social structure and population composition. The source of the material for the country profiles used in this activity was publicly available material developed for an online role-play-simulation (Project IDEELS) which was designed to explore issues around the integration of European countries. So while country profiles were badged with fictitious names, they had strong linkages to actual countries.

The learning objectives for the Scenario Building exercise were:

- Promote awareness of the economic, technological, social, political and environmental factors which impact the chosen topic;
- Develop skills in working with qualitative and quantitative data;
- Recognise where sources of conflict or controversy can arise in trying to reach consensus.

Students worked on the scenario building exercise in groups of four. The groups were chosen by the subject coordinator to ensure there was a mix in each group of different engineering sub-disciplines. This approach was undertaken in an attempt to maximize the student diversity within each group.

The exercise was divided into three stages:

1. *Identification of Key factors (Stage 1)*: Students identified STEEP (Social, Technical, Environmental, Economic and Political) factors relevant to their topic. They then presented these to other groups and debated their relevance to the topic they were given.
2. *Integration of Key factors into background material. (Stage 2).* Each key factor was further partitioned into categories so they could be integrated into the country profiles. This was presented in a matrix as well as in an extended written description.
3. *Issues arising from scenario integration (Stage 3).* Students then had to identify what issues could arise if common agreements needed to be reached between the countries regarding integration of their particular engineering technology. This often drew out some of the value-laden implications of technological development due to the diversity of the social and biophysical data in the profiles.

Informal feedback from the students suggests they found it a worthwhile exercise for developing their understanding of socio-technical relationships. They would often comment on the debate that occurred when they tried to agree about matching technological developments with societal characteristics. The exercise appears to be successful in incorporating both deliberation and representation into learning process. The engineering students got particular expertise in working with the qualitative social and biophysical data to describe the relationship between the technological issue and the societies it would impact.

COMPARISON OF DIFFERENT INSTRUCTIONAL STRATEGIES

The three different instructional strategies presented in this paper have been successful in getting students to identify different perspectives (e.g. economic, social, environmental) on a complex engineering problem and then integrating the diverse data and values which underpin those perspectives together. In this way the goals associated with each of the economic, social and environmental dimensions of engineering projects are accommodated within the instructional activity undertaken. Creating the conditions in the engineering classroom under which there is sufficient diversity in data, beliefs and values for these types of activities can be a challenge. Both the Mekong e-Sim and the SAC are role-based activities where a diversity in perspectives can be created through student representing different personas. In the Mekong e-Sim additional diversity was introduced through having student engineers and geographers participate. The SAC and Scenario Building exercise involved engineers from different sub-disciplines. In each case whether it was through the disciplinary background of the student cohort, the nature of the problem or the adoption of roles in the activity there was sufficient diversity in perspectives to create the required outcomes for learning about sustainability.

The learning design and stages within both the SAC and the Mekong e-Sim have similarities. Students adopt a role, critically analyse the situation, argue positions and then synthesize their understanding. Student responses to both activities indicate the development of multiple perspectives and knowledge-seeking from a range of sources (Table 1, Table 2). However the SAC has less focus on simulating the context of the decision-making environment than the Mekong e-Sim. The addition of an 'Interaction stage' into the e-Sim gave students an opportunity for deeper immersion and to further formulate and make operational their understanding of their adopted personas in the activity. This is reflected through an additional learning objective for the e-Sim relating to the 'responsibilities and responses for characters in the roleplay-simulation'. Students strongly agreed that their knowledge and values awareness about organizations in the region was developed by the activity (Table 1).

Design of the learning activity in the SAC has a more explicit focus on developing critical thinking skills than in the e-Sim. This came out of the SAC reflective stage, where students were required to present views which both support and refute those held by their adopted persona, while in the e-Sim there was a greater focus on the awareness of different aspects of complex engineering problems and their linkages. These differences reflect the underpinning pedagogy of the activities. The SAC forum has a greater similarity to a traditional debate while the roleplay-simulation has a much greater professional and contextual richness due to its stronger links to simulation. The scenario building exercise had a very different learning design. Students had much lower levels of structured interaction between the groups and worked with data provided by the lecturer rather than generated by other students. This activity had a focus on project-based learning, report writing and skill development in handling different types of data while still providing learning about sustainability.

CONCLUSIONS

Moving towards sustainability in our engineering curriculum will require significant changes. To integrate fully sustainability at a subject level requires both sustainability content (principles and concepts) as well as suitable learning strategies. A focus on how we teach as much as what we teach is important if we are to educate for sustainability. Active learning strategies, which involve participatory methods including the ones described in this paper can be effective in creating the integrated and interdisciplinary perspectives required for learning about sustainability. The instructional techniques described in this paper are applicable to many subjects that deal with issues of science, technology and society interaction. They are especially useful when there is diversity within the types of knowledge and value systems of the student cohort

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