Embedding Sustainability in Civil and Environmental Engineering Courses

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Abstract

To sustain human civilization into the foreseeable future, the education of the engineering leaders of tomorrow needs to include sustainability so that the full consequences of engineering decisions and actions are considered. Sustainability is a dynamic characteristic of a system that must be assessed and managed over time. All resources available to development must be considered when engineering of systems is being undertaken. In this paper, a new approach to assessing to what degree sustainability principles have been embedded into engineering degree programs is introduced and applied to the Civil and Environmental Engineering degree program at the University of Adelaide. The results obtained indicate that there is a high degree of embedment of sustainability principles in the degree program. From first year, the lecture material on problem solving, sustainability and mind mapping leads the students through open ended problems that many engineering problems fall within. Through subsequent years, the social, economic, environmental and infrastructure aspects of sustainability are addressed in greater detail. At level four, groups of students choose to research aspects of sustainability in their major research projects. Many graduates of this program have made sustainability in their respective organisations a main theme of any work they perform.

1. Introduction

In order to maintain current living standards in developed countries, and increase the quality of life in developing countries, sustainability needs to be at the core of all engineering activities. Sustainability is a dynamic characteristic of a system that must be assessed and managed over time. All resources available to development must be considered and therefore the education of engineers needs to acknowledge the complexity of available resources and the interactions between those resources and adjacent systems. In 1997, the *Australian Academy of Technological Sciences* issued a report[1] to government on the status of scientific and technological (including engineering) education with respect to its focus on sustainability, which made recommendations for changes to curricula and program content and context. There were specific recommendations for science education, but many recommendations were made for changes to all disciplines of engineering education. The report[1] recommends that all engineering students need to be taught to consider and evaluate the use of all resources, considering the limited resource constraint, recycling, alternative resources and global sustainability. The report states that it is necessary to prepare ". . *young engineers to accept sustainability as a basic design requirement for the development of products and processes* *and as a basic policy criterion for future industrial developments*"[1]. Engineers Australia's Policy on Accreditation of Professional Engineering Programs[2] supports these recommendations by including the following two generic attributes that Graduates require from an accredited engineering program:

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

The definition of sustainability considered is paramount for any discussion on how sustainability is being incorporated into engineering education. In this paper, it is considered that the most appropriate approach to sustainability is a systems approach, as described by Foley et al.[3] A systems approach to assess sustainability is not a new method, and has been applied in certain sustainability assessments since The Club of Rome[4] in 1972. The systems approach is generally used in solving engineering problems and provides a simple and consistent basis for the integration of sustainability at all levels of society, from the global scale to the individual scale. Using a systems approach, Gilman[5] provides the following definition of sustainability:

"*Sustainability refers to the ability of a society, ecosystem, or any such on-going system to continue functioning into the indefinite future without being forced into decline through exhaustion or overloading of key resources on which that system depends.*"

This definition, unlike many sustainability definitions, can be applied to any system and provides an excellent platform for the following discussion and analysis.

By adopting a systems approach to sustainability, sustainability principles can be embedded into engineering degree programs with relative ease. The embedding of sustainability in a program addresses the concerns of Barger and Hall[7] of including these issues as separate courses in the engineering programs which are already overcrowded and underfunded. However, there are difficulties in assessing to what degree sustainability has been embedded into engineering degree programs. In the past, conventional training in the use of technological solutions for infrastructure considered life cycle costing and economic analysis, but now is more firmly integrated with the environment, economics and social issues when managing the life of a project. When teaching the design process, the elements of critical thinking and problem definition are now stressed more than they were in the past. In defining the problem, the impact on adjoining systems, both now and in the future, are considered. Different academics will give different emphasis to either fundamental technical skills, holistic thinking, critical analysis and synthesis of information or whatever is their area of expertise. It is essential, therefore, that students get exposed to different approaches to problem solving, so that there are alternatives for problems of varying difficulty.

In this paper, a new approach for determining to what degree sustainability has been embedded into engineering degree programs, which is based on the systems model of sustainability developed by Foley et al.[3], is presented and applied to the Civil and Environmental Engineering degree program at the University of Adelaide, Australia.

2. Proposed Approach

Traditional models of sustainability consider the interdependence and interaction between environmental, economic and social systems. However, if sustainability is recognised as a characteristic of a system, then a thorough understanding of the systems involved in any project is required. In the present discussion, the systems of interest are engineering systems, such as those associated with urban developments (e.g. water resource systems), transport systems, sewerage systems and energy systems. Consequently, system sustainability in the context of engineering must also make provision for infrastructure. This is an agreement with Jeon and Amekudzi[6], who, when addressing the sustainability of transportation systems, demonstrated the importance of including infrastructure as a major element of sustainable systems. The findings from this paper indicated that there is an important role for education as a critical tool for moving social/infrastructure systems toward sustainability. It also highlighted that capturing infrastructure security was a critical component of sustainability in infrastructure systems. Consequently, the systems model defined by Foley et al.[3] is used as a basis for assessing to what degree sustainability is embedded in engineering curricula as part of the approach proposed in this paper, as it encapsulates infrastructure systems with those of the environment, social and economic systems, as shown in Figure 1.

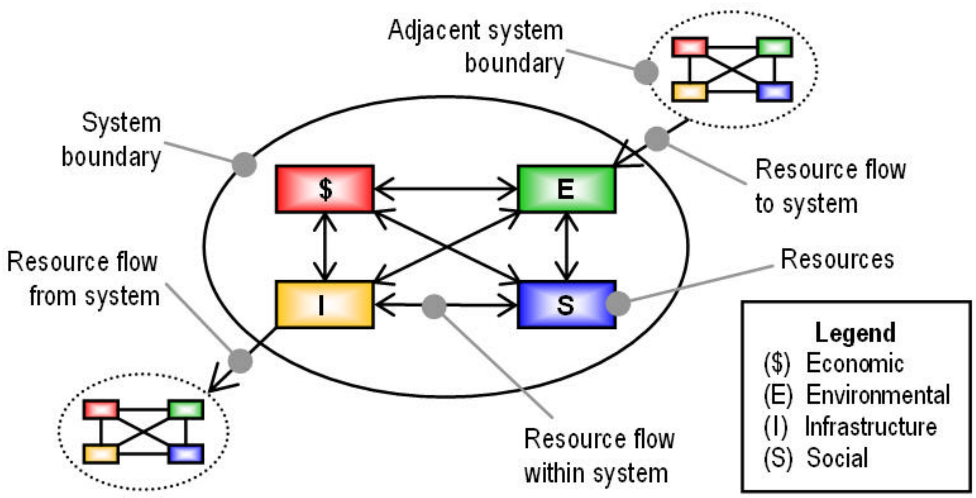


Figure 1: Systems Model of Sustainability (Foley et al.[3])

In understanding how a system functions, it is necessary to focus on the system resources. Resources are considered to be any component of a system that is important to the functioning of that system. These include natural resources, but also human resources, financial resources and manufactured or human-made resources, such as physical infrastructure and manufactured goods. Manufactured resources exist in all human systems and play a critical role in the processing of resources within a system. The existence of civilization depends on these manufactured resources. If the infrastructure were to fail, it affects the ability of both the individual engineering system, and the people who depend on it, to continue to function satisfactorily.

Infrastructure has a defined risk of failure, and failures can come from various sources, including natural disasters, lack of maintenance and acts of war. The ability of a system to absorb these failures is dependent upon the adaptability of the system resources and the engineering of them. These adaptive elements of a system need to be recognised and then included in the development of a solution. Consequently, problem solving skills, including both analysis and synthesis to develop sustainable solutions, are required in the training of engineers.

As part of the proposed approach, the basis for assessing to what degree sustainability has been embedded into engineering curricula is the separation of the four elements of the model in Figure 1, and subsequent determination of the extent to which each of the four aspects of sustainable systems are addressed in each course. This assessment gives an indication of which courses address some, or all, of the 4 aspects of sustainable systems (not just 1), and how the 4 aspects are addressed over various courses in the entire degree program. There is the basic assumption that, if all aspects of sustainable systems, and importantly, the linkages between them, are addressed throughout the degree program, students will have a good understanding of sustainability principles and how to apply them in practice.

The proposed methodology includes the following steps:

- Adopt a scale ranging from 0 to 5 for each of the 4 aspects of sustainable systems (i.e. infrastructure, environmental, economic, social). The scale has the following meaning: 0 = not addressed, 1 = some awareness developed, 3 = moderate emphasis, 5 = strong emphasis;
- Ask each course co-ordinator to perform a self assessment, giving a rating from 0 to 5 for each of the 4 aspects of sustainable systems for her/his course. In addition, ask for a brief commentary as to why the various ratings were given, based on the course content; and
- Compile a matrix of ratings for each of the courses to assess how well aspects of sustainability are embedded into degree program.

3. Case Study

The methodology for assessing how well aspects of sustainability have been embedded into engineering degree programs introduced in Section 2 has been applied to the Civil & Environmental Engineering degree program at the University of Adelaide, Australia. The four year degree program is divided into a number of streams, as shown in Figure 2. At the core of the program are courses on natural resources and infrastructure, as the provision of infrastructure and the management of natural resources is central to civil and environmental engineering activities. The courses on natural resources and infrastructure consist of four streams, namely environmental, water, geotechnical and structural engineering. The courses on natural resources and infrastructure are supported by courses on engineering management, engineering modelling and analysis, science and mathematics to provide the necessary background skills.

As can be seen in Table 1, there is a progressive shift from developing the supporting skill base towards specialist courses in the Natural Resources and Infrastructure stream from years 1 to 4. In addition, in the Civil and Environmental Engineering program, there is increased emphasis on water and environmental engineering courses in the later years of the program.

In this study, the courses in the Engineering Management and Natural Resources and Infrastructure streams were assessed using the method introduced in Section 2.

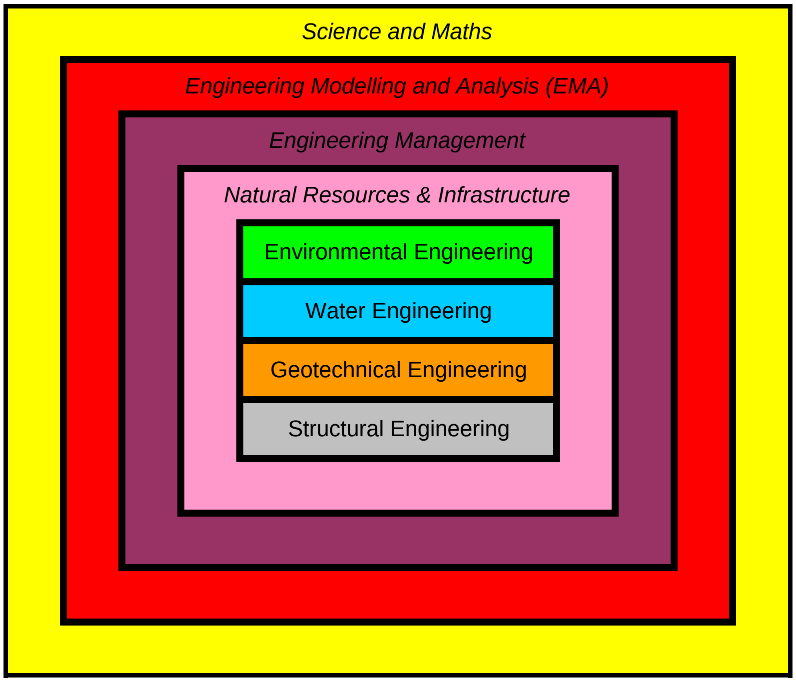


Figure 2: Structure of Courses in Civil & Environmental Engineering Program, University of Adelaide

4. Results and Discussion

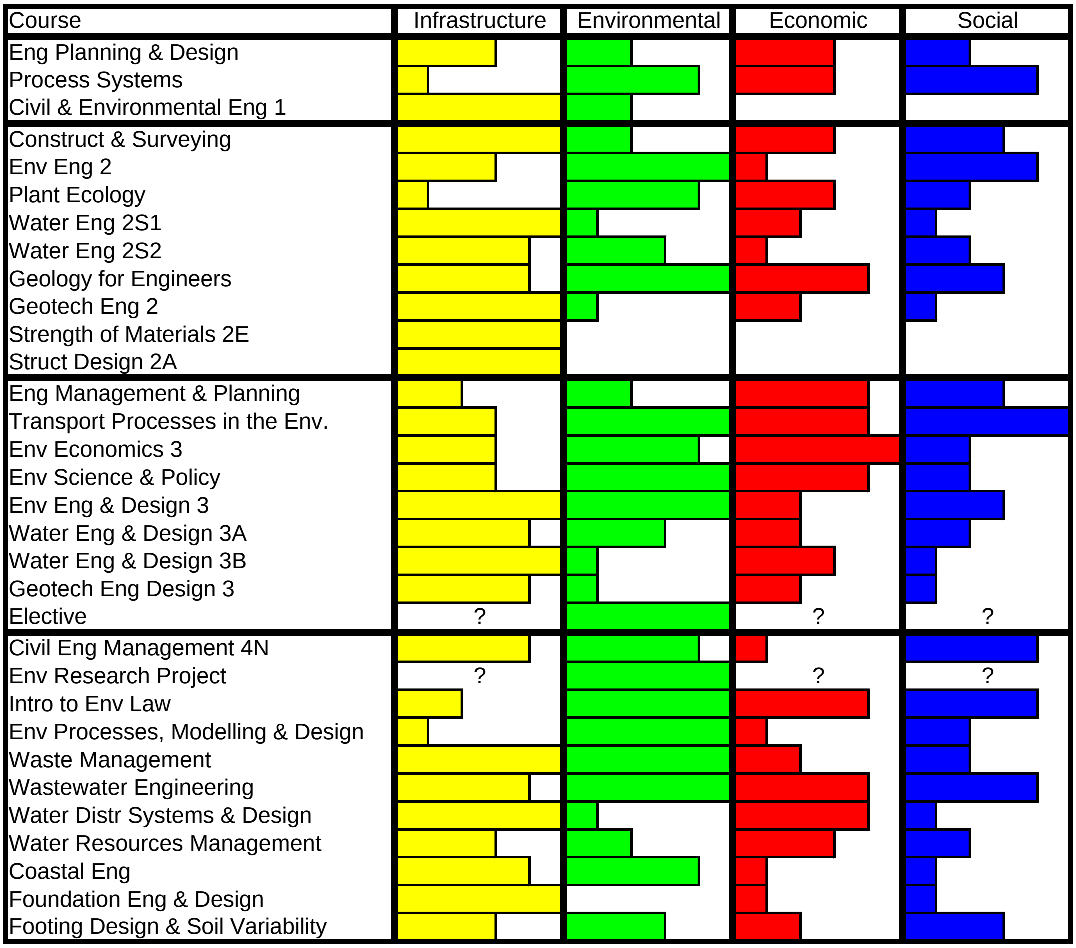
The results of the sustainability assessment are shown in Table 2. It can be seen that there is a good coverage of all four components of sustainable systems over the entire degree program. There is moderate to strong emphasis on infrastructure and the environment throughout the entire degree program, with an increased emphasis on environmental components at higher year levels. In some courses, such as Water Engineering IIS1, Water Engineering IIIB and Water Distribution Systems and Design, the major emphasis is on the provision of infrastructure (e.g. analysis and design of water supply systems), with the environmental component consisting of a discussion of potential impacts of this infrastructure on the environment (e.g. materials used for infrastructure provision, impact on natural resource). In other courses, such as Environmental Engineering II, Plant Ecology, Geology for Engineers and Environmental Processes, Modelling and Design, the emphasis is on the importance, understanding, protection and restoration of environmental systems, while considering the potential impact of infrastructure on such systems and how to minimise these. In some courses, such as Environmental Engineering III, Waste Management and Coastal Engineering, there is equal emphasis on the infrastructure and environmental components. This is generally because the purpose of the course is to introduce engineering measures as a means of preventing or reducing environmental problems.

Table 1: Courses in Civil and Environmental Degree Program, University of Adelaide

Year	Maths & Science	Eng Modelling and Analysis (EMA)	Eng Management	Natural Resources and Infrastructure			
				Environmental	Water	Geotechnical	Structural
1	Chemistry 1A	EMA 1	Eng Planning & Design	Civil &	Environmental	Engineering	1
	Env Biology 1	Statics		Process Systems			
	Maths 1A	Dynamics					
	Maths 1B						
2		EMAII	Construct & Surveying	Env Eng 2	Water Eng 2S1	Geology	Strength of Materials 2E
				Plant Ecology	Water Eng 2S2	Geotech Eng 2	Struct Design 2A
3		EMAIII	Eng Management & Planning	Env Economics 3	Water Eng & Design 3A	Geotech Eng Design 3	
				Env Science & Policy	Water Eng & Design 3B		
				Env Eng & Design 3			
				Transport Processes & the Environment			
				Elective*			
4			Civil Eng Management 4N	Env Research Project	Water Distr Systems & Design**	Foundation Eng & Design**	
				Intro to Env Law	Water Resources Management**	Footing Design**	
				Env Processes, Modelling & Design**	Coastal Eng**		
				Waste Management**			
				Wastewater Eng**			

* Electives Include: Ecosystem Modelling, GIS for Environmental Management, Catchment Management
** Students choose 4 of these courses

Table 2: Sustainability Assessment of Courses in the Civil & Environmental Degree Program



? = Variable (Depending of elective / project chosen)

While only one course has economics as its main emphasis (Environmental Economics III), there is moderate to strong emphasis on economics in almost half of the courses (14 out of 30), with a further 12 courses raising some awareness of economic issues. While some of these courses cover economic theory, in the majority of cases the economic component relates to the design and costing of infrastructure and the economic impacts of environmental degradation and restoration. No course has social systems as its main emphasis, however, the majority of courses raise awareness of, or place moderate emphasis on, the social impacts of engineering projects.

An important aspect of the systems model of sustainability upon which the assessment conducted in this paper is based is the need to consider the interaction between the four components of sustainable systems. However, the degree of this interaction is not captured in the assessment shown in Table 2. In order to illustrate how these linkages are made, the content of some of the courses at various year levels are discussed in more detail below, including Engineering Planning and Design, Environmental Engineering II, Geology for Engineers and Civil Engineering Management 4.

In Engineering Planning and Design, mind mapping, creative and critical thinking, simple models of sustainability, economic analysis, environmental and social considerations and criteria are presented, as are professional ethics required of an engineer. The interaction between these topics is emphasised in a concurrent project that requires the students to work in a team and prepare an engineering report. Sustainability is embedded in the examples that are given when outlining how an engineer carries out the design process when assessing alternatives. Similar courses such as this have been included in other programs, as described by Siller[8].

A feature of Environmental Engineering II is the Mekong e-Sim, which is a distributed, computer supported roleplay/simulation and involves approximately 60-140 students with various technical backgrounds from a number of universities (e.g. University of Adelaide, University of Technology, Sydney, University of Sydney, Sepang Institute of Technology), who adopt the roles of stakeholders (e.g. government organisations, engineering firms, non-government organisations, media groups etc.) and respond to proposed development issues (e.g. the proposed building of a large dam) in the Mekong River basin. Through research and interaction with other persona, participants build a case as to whether the proposed development should proceed or not, which they present and defend during an on-line public inquiry. As part of this process, students learn a number of generic skills, such as communication, research, groupwork and critical thinking, as well as technical skills in a particular area (e.g. the impact of dams on fish migration). In addition, participants learn to see multiple perspectives surrounding an issue (e.g. social, political, environmental, economic, cultural, ethical, technical) and through debriefing and reflection, gain an understanding and appreciation of the complexity of decision-making processes surrounding development issues. For engineering students, it also provides first-hand experience of the role of engineering in society and the potential social and environmental impacts of engineering projects. As a result of the high degree of interaction between stakeholder groups, and the sharing of the various points of view surrounding the proposed development, students gain an appreciation of the need for sustainable development, as well as a good understanding of what sustainable development entails.

The course Geology for Engineers examines the drivers that affect Civil and Environmental Engineering projects, such as responses to social and economic pressures, and how such projects interact with and modify environmental systems. The course is based around case studies that examine the drivers for the development, and the environmental impact of, a range of infrastructure projects, such as roads, tunnels and buildings. Some of the case studies have included the Adelaide-Crafers tunnels, water allocation decisions in the Artesian Basin, siltation of the Murray mouth and the clean water levy, modification of the Gulf St Vincent foreshores by urban development and the economic and social consequences of good and poor mine design (pits, tunnelling, caving methods).

The course Civil Engineering Management 4 includes a project proposal component, which sets up criteria that require sustainability to be considered in the solutions being proposed. Although the main emphasis is on how groups of students work together in teams, it gives these final year engineering students the chance to discuss sustainability issues in order to win the project against other teams. By embedding the criteria into the assessment, the students consider sustainability as a desired outcome. The types of projects have included wind farms, solar power generation schemes, redevelopment of city centres and transport systems.

Overall, the results in Table 2, and accompanying discussion, indicate that there is a large degree of embedment of sustainability principles in the Civil and Environmental Engineering degree program at the University of Adelaide. While the major emphasis in the degree program is on the environmental and infrastructure components of sustainable systems, moderate to strong linkages between all four components are evident throughout the degree program. This is because in developing the degree program, a process-based approach has been adopted, which embeds the tools for achieving sustainability in the normal design and problem solving processes of engineering. It thus becomes a natural part of all aspects of professional engineering practice once students graduate.

It should be noted that the ratings contained in Table 2 are based on a self-assessment of the courses by the various course co-ordinators, and while care has been taken to develop a shared understanding among the course coordinators of the systems model of sustainability and the rating scale used, which was done through written documentation and, in some instances, face-to-face or telephone discussions, there might be some inconsistencies in the assessments. However, it is unlikely that these inconsistencies have a significant impact on the overall assessment of the degree of embedment of sustainability in the degree program.

Another factor worth pointing out is that discussions with some of the course coordinators revealed that, although they raise awareness of and/or emphasize the linkages between the four components of sustainable systems, they do not explicitly refer to sustainability, and, in some instances, are not aware that they are addressing aspects of system sustainability. Consequently, there is a need to increase teacher awareness of sustainability, and for teachers to highlight to students how aspects of sustainability are addressed in their course.

A potential change resulting from this assessment is the inclusion of various facets of sustainability in each course through designs and projects and increasing the awareness of students of this. A major step yet to be undertaken is to ask the students through a short evaluation of whether they are able to recognise the embedded nature of sustainability in the degree program. Future plans also include the inclusion of the sustainability ratings in course outlines in order to raise awareness of sustainability, and how it is addressed in a particular course, of both students and teachers.

4. Conclusions and Recommendations

In this paper, a new approach for assessing the degree to which sustainability principles are embedded into engineering degree programs was introduced and applied to the Civil and Environmental Engineering degree program at the University of Adelaide. It was found that there is a high degree of inclusion of sustainability in the degree program. However, this assessment is the first step of recognition of sustainability in the Civil and Environmental program. The next step is to assess the impact on students and how the program has developed their awareness of sustainability. This could be done through surveys at the end of the degree program and after they have worked for a few years to find out how they have applied sustainability principles in practice. However, there is already some evidence of the success of embedding sustainability in the Civil and Environmental program at the University of Adelaide, as indicated by the career paths of past graduates.

There is still much to be done and a few activities, such as embedding participatory methods in sustainability, embedded energy in design solutions for structural designs, full assessment of social implications of engineering decisions and how to include stakeholder interactions in developing engineering solutions to the development of infrastructure systems into existing courses. In general, the main concern with adjusting course content is that for every item that is added there has to be something that is dropped. However, with the sustainability issues, this is not so, as in most cases, it is a need to analyse more deeply the decisions that are being made, as would be done in practice. As time progresses, most courses should have examples of sustainability built into them, including basic core courses such as mathematics.

Acknowledgments

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