AC 2011-2465: INTRODUCING ELEMENTS OF SUSTAINABILITY INTO FORMAL AND INFORMAL ENVIRONMENTAL ENGINEERING EDUCATION

Jean D MacRae, University of Maine

Jean MacRae is an Associate Professor of Civil and Environmental Engineering at the University of Maine, where she is faculty adviser of the student chapter of Engineers Without Borders.

Introducing elements of sustainability into formal and informal environmental engineering education

The pressing need to find ways to improve quality of life on a crowded planet with energy and resource limits provides the impetus behind at least five of the National Academy of Engineering's Grand Challenges[1]. Bolstering students' understanding of what constitutes sustainability is therefore an important aspect of an engineering education and can contribute to ABET outcomes c (an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability) and h (the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context)[2]. The importance of sustainability in environmental engineering decision making has therefore been emphasized in a technical course, and a non-technical course was designed to explore sustainability issues in a global development context. Student participation in Engineers Without Borders (EWB), a service organization with a mission to provide sustainable engineering solutions for developing communities, also provides informal learning opportunities.

These three venues provide different contexts in which to understand sustainability. Their different emphases produce varying perspectives on sustainability and different levels of awareness, especially about the social impacts of engineering design and practice. This paper provides a reflection on the ways in which the environmental, social and economic aspects of sustainability appear to lend themselves best to each of these contexts.

Environmental sustainability has been most heavily and effectively emphasized in the technical course, since material and energy balance approaches can readily be used to assess sustainability, and the concepts of ecosystem services and resilience fit well within the scope of the field. Group projects encourage the exploration of sustainability issues including energy, water and resource use and management, biodiversity, resilience, ways to reduce negative environmental impacts and assessment techniques to "measure" sustainability.

The international context of the EWB project and non-technical class brings the cultural and social aspects of sustainability into relief, so they are easier to recognize and acknowledge. Typically in the club context, the economic aspects are prioritized due to the scarcity of funds, and social acceptability is a major factor in design, however levels of awareness among club members vary considerably. The non-technical course provides an opportunity to read and reflect on what makes a project successful in the long-term. The emphasis has been on the social, including economic, aspects of sustainability. Environmental sustainability is also discussed, but with less emphasis on mechanism due to differences in student programs and background understanding. The classroom setting provides common content that can be used as the basis for discussion of issues and assessment of sustainability, but the EWB project provides a powerful motivation to learn. The limited grade and survey data available suggest that the formal and informal settings are mutually supportive in that students who are involved in EWB have a greater motivation to engage in the intellectual work of the formal class, and the students who have been in the class are likely to become more productive EWB members.

Motivation to introduce elements of sustainability into environmental engineering education

The word "sustainability" is widely used in a variety of contexts and fields, ultimately meaning different things to different people. This lack of clarity results in misunderstandings and in some cases misuse of the word. The ambiguity stems largely from the breadth of the most widely used definition of sustainable development, which derives from the Brundtland report: development which "meets the needs of the present without compromising the ability of future generations to meet their own needs"[3]. Taken from different narrow disciplinary points of view, or at short time scales, this definition can mean very different things and may be taken in widely disparate ways. Furthermore, predicting what future generations will need or even defining what constitutes a current need can be debated. Once the problem is identified and defined, a solution will only be both practically applicable and sustainable if it does not deplete natural resources or harm ecological systems while being acceptable to affected human populations.

It is particularly important to develop a clearer and more comprehensive concept of sustainability because physical evidence and modeling suggest we are approaching a number of limits which could compromise global life support systems (for example see ref. 4). To manage and lessen the impacts of change, we will all have to be more mindful of the constraints imposed by the environment and society as well as the economy on our actions, plans and designs. The need for engineers to address this issue was underlined when the National Academy of Engineering identified 14 Grand Challenges facing society. The report states: "Foremost among the challenges are those that must be met to ensure the future itself. The Earth is a planet of finite resources, and its growing population currently consumes them at a rate that cannot be sustained."[1], and the first five challenges: (1) make solar energy economical, (2) provide energy from fusion, (3) develop carbon sequestration methods, (4) manage the nitrogen cycle, and (5) provide access to clean water, are all related to sustainability. It is, however, possible to work on these important issues without really contributing to overall sustainability by defining the problem boundaries too narrowly rather than assessing potential solutions from a broad system perspective.

With this context in mind, one course was altered and another was developed to deal more deliberately with sustainability issues. They are: CIE 231 Fundamentals of Environmental Engineering and GEE 250 Sustainable Solutions for the Developing World. The first is a required, sophomore level (in the process of being shifted to junior year as CIE 331) introduction to environmental engineering taken by all Civil and Environmental Engineering majors and a relatively small number of students from other disciplines. Enrollment for the class is typically between 70 and 90 students. Sustainable Solutions is a non-technical elective course that meets University of Maine general education requirements for Cultural Diversity and International Perspectives, and Population and the Environment, which has been taken by students from a variety of majors at different stages in their programs. The latter course was designed specifically to provide support for the University of Maine chapter of Engineers Without Borders (EWB-UMaine), and enrollment is capped at 25.

Ways in which sustainability was incorporated into the courses

Sustainability issues have always been raised in Fundamentals of Environmental Engineering but in the most recent iteration of the course, the theme of sustainability was used to frame the course content in the first week of classes, and two group projects were introduced which allowed groups of students to explore different aspects of sustainability in greater depth. The newly adopted textbook, Environmental Engineering: Fundamentals, Sustainability, Design[5] also supported this change in emphasis and provided a starting point for the students to collect information for their presentations. The course technical content is standard, covering unit conversions, basic aquatic chemistry, kinetics, mass and energy balances, and basic ecological concepts, as well as briefly introducing the scope of the environmental engineering field. These topics are all required to prepare students for advanced environmental engineering courses.

The course has long been designed to provide examples from practice, theoretical foundations required to solve problems, and time in class for groups to solve problems related to the material. A typical class period involves some lecture on content, several problems, some question and answer and discussion time. Prior to the reorganization, assessment was based on homework and some in-class assignments, exams and quizzes on the readings. The current version moved the quizzes on-line and included the two presentations. Less time was spent on environmental engineering practice as separate units in the course, so more examples from practice were used to illustrate the relevance of fundamentals as each new topic was introduced.

Beginning the most recent iteration by framing the course content in the context of sustainability was intended to link the material to issues that are important to the students as well as provide ties with material covered in other courses. Examples of how the fundamental content could be applied referred often to sustainability. The initial framing began with a screening of the PBS e^2 design episode called “China: from Red to Green?”, which links energy and water issues with building and community design[6]. A brief discussion followed on how sustainability considerations, including the environmental and human dimensions in addition to economic and materials decisions, must be considered in all aspects of civil and environmental engineering design. Students also reflected on how relevant the issues raised in the film are at home. In addition to framing the course content, this video also linked sustainability and environmental engineering practice to other concentration areas in civil engineering. This aspect of sustainability was chosen to provide relevance to students who were less intrinsically interested in the environmental field to try to stimulate the caring aspect of Fink’s taxonomy of significant learning[7]. The format should also stimulate the interest of visual learners as described by Felder[8]. A broader description of the environmental economic and socio-cultural elements of sustainability, evidence of climate change, extinction rates and dead zones, which underscore the need for change, and the need to approach design in different ways followed. This material emphasized the need to think broadly about the implications of engineering decisions, consider the context of a given solution and the need for creativity. Again, the intention of this approach to framing the course content was to get students to engage and motivate them to put in the time and work needed to do well. Motivating students to engage is very important in this class because this population of students tends to be poorly prepared in chemistry and biology, so many find the course frustrating since it doesn’t come as easily as more physically based material.

The presentations were on topics chosen by groups of students (see suggested topics in Table 1). The element of choice was important so that students could research topics that were of interest to them, underscoring the connections between the course content and their interests and goals. A short paper was also assigned on the same topic to encourage students to reflect more deeply about the subject matter and provide the opportunity to practice professional/technical communication in both the written and oral/visual forms.

Table 1: Sustainability-related group presentation topics

Presentation 1	Presentation 2
• Water scarcity • Energy usage • Poverty • Population growth • Urbanization • Climate change • Toxic, persistent chemicals • Use of finite resources • Tragedy of the commons • Water quality	• Risk Assessment • Industrial Ecology • Life Cycle Assessment • Building design to reduce impacts • "Green" materials (be specific) • Design for energy efficiency • Energy-water linkage • Sustainability indices (measurement) • Resilience • Policy to drive green engineering • Urban planning to reduce impacts

The overall grades for the course were not affected by the change in format, however the level of agreement with the statement "I have an improved understanding of human impacts on ecosystems" was higher on average (3.91 vs 3.50 on a 5 point scale; significant at the 95% confidence level) in the modified course. Student in the modified course were also more confident in their problem solving skills (3.74 vs 3.38), and found the subject matter more interesting (3.24 vs 2.85).

As is evident by the presentation topics in Table 1, the emphasis of the sustainability context included in this required technical course was on environmental aspects with much weaker inclusion of economic and social sustainability. This was primarily due to the fit with the course content required as background for advanced courses in environmental engineering. Social and economic issues do come up in this context but they were not explored in a directed or systematic manner, and there was no real opportunity to provide a theoretical framework or take time for reflection on these aspects, as required for significant learning[7].

Sustainable Solutions for the Developing World was created at the request of student members of EWB to provide them with an opportunity to learn about sustainability in the context of international development engineering in a formal way. It is a small, non-technical, readings- and discussion-based course which provides background on elements of environmental, social and economic sustainability, development, gender and cultural issues, and encourages students to critically evaluate the sustainability of EWB projects based on project reports. The first half of the class is primarily acquisition of a common understanding, vocabulary and methodology to discuss relevant issues. Later, the insights gained are applied to the analysis of EWB project reports from UMaine or available from other chapters on the web. The class participants then provide their recommendations to EWB-UMaine on how to strengthen the project and approach. Students in the class also write a report and present on an "appropriate technology" of their choice and comment on its applicability in different contexts. All EWB members and the campus community are invited to attend the presentations. A list of topics and readings used in the first half of the course is shown in Table 2. The remainder of the course is spent discussing projects, best practices and developing recommendations for the EWB chapter.

Table 2. Topics and Readings used in Sustainable Solutions for the Developing World

Topic	Readings
• Definitions: quality of life, development, culture and sustainability, sustainable development	• Various sources – found by students
• Environmental sustainability	• Class notes
• Economic sustainability	• "Dimensions of world food and development problems", " Economic transformation and growth"[9]
• Social sustainability	• "Sustaining livelihoods and human well-being during social–ecological change"[10]
• Indices of sustainability and development	• Various sources – found by students
• Millennium development goals	• UN MDG web site[11]
• Life cycle approach to sustainability in development	• " Adapting life cycle thinking tools to evaluate project sustainability in international water and sanitation development work."[12]
• Women, community input and access	• "Building with the Community: Engineering projects to meet the needs of both men and women."[13]
• Elements of culture	• "Culture Matters" [14]

To ensure that students did the readings and were well prepared for the discussions, homework assignments (due at the beginning of the class) were mostly of two types. One required students to read the assigned reading and answer questions about the reading which drew their attention to issues that were to be discussed during the class period. These assignments effectively prepared the students for the discussions, increased participation since they had already considered important aspects of the topic, and allowed them to identify concepts or issues they did not understand so they could seek clarification. Most of the class discussions were quite lively and most students were willing to participate actively without needing to be called upon. The other type of homework assignment involved sending students to various sources to gather information on a particular topic. The students particularly enjoyed their discussions on indices and measurements of sustainability. These were explored on two consecutive classes. In the first, the students described their research topic mostly following the formula and topics outlined in the homework assignment. The completed assignments were distributed to all class members, and in the second class meeting, the relative merits, strengths and weaknesses of different approaches were discussed. In the case of sustainability indicators these discussions provided some models with which to compare the United Nations millennium Development Goals and indicators.

Since this course deals extensively and explicitly with sustainability issues, it is not surprising that the students in this class agreed more strongly with the statement "I have an improved understanding of human impacts on ecosystems" than students from the Fundamentals of Environmental Engineering course described above (4.50 vs 3.91 on a 5 point scale; significant at the 95% confidence level). This difference might be influenced by the overall attitude of the students taking the courses, which were more positive toward the subject matter in the case of the elective Sustainable Solutions than of the required Fundamentals of Environmental Engineering, according to the course evaluations (4.33 vs 3.24). Students in the Sustainable Solutions course also agreed strongly with the statement "I can apply a life cycle approach to a project to ensure all aspects of sustainability are considered in design and implementation of a project" (on average 4.7/5).

Sustainable Solutions students who were involved in EWB had, on average, slightly higher grades (89%) than the whole class average (86%), however the numbers of students were small and the difference was not statistically significant.

Sustainability issues in the EWB-UMaine context

EWB-UMaine provides an opportunity for engineering and other students to learn engineering, planning, communications, fundraising, leadership, interpersonal and professional skills while contributing to projects which aim to improve quality of life in developing communities. Since sustainability is a cornerstone of the organization's mission, participants also consider these issues in the planning, design and assessment phases of the project. The informal nature of participation in this volunteer activity has both advantages and disadvantages. It generally means that the participants have strong intrinsic motivation to successfully complete the project, but they come to the group with different levels of experience and competence, which presents membership and project-related challenges to the leadership that they are not always well prepared to manage. Two particularly difficult aspects of organizational sustainability are efficiently integrating new members into projects so they can contribute in a meaningful way and motivating all members to participate in fundraising activities.

The UMaine EWB project is a neighborhood sanitation system for a small peri-urban development in western Honduras. Students who have travelled to their partner community have come back highly motivated and have worked hard, in several cases even after graduation, to ensure that the project is successfully completed. The main sustainability issues that have been widely understood and explicitly addressed by the group are: (1) the social acceptability of the system and maintenance requirements, (2) minimization of the operation and maintenance costs of the system, and (3) the use of materials and construction methods that are available locally. After looking at the sanitation options open to the community, EWB-UMaine favored the use of composting toilets to eliminate the use of water, which is scarce during the dry season, for flushing. The community was unwilling to use this option however, so their preferred option (septic tanks and a raised mound leach field) has been designed instead. This outcome underlined the importance of the social acceptability of a technical solution. The maintenance of the system, which requires annual pumping of the septic tanks, was thoroughly discussed at community meetings and viewed as acceptable. The residents have a variety of investment needs, so the system was designed to have minimal operational and maintenance costs and the labor involved in system upkeep will all be provided by community members. There is a system in place to pay for repairs, but the ongoing costs of the system should be small and manageable, and the whole system fits on a plot of communally-owned land. To the maximum extent possible, the design uses materials that can be produced or obtained locally so any repairs can be done without needing to go to external sources. As new students join the group these aspects tend to need to be revisited until the importance of sustainability is understood by all involved.

Synergy between course work and EWB

Six of the 31 students who have taken leadership roles in the four year history of the UMaine chapter of EWB first learned about the club through the Sustainable Solutions class, which has only been offered for three years. Students who have taken the course have also been more consistently mindful of sustainability issues in design decisions, trip planning and in chapter communications with the partner community than chapter members who have not. The feedback that EWB has received from the course participants has been very thoughtful and in cases quite insightful. Active members simultaneously taking the course and working on the project have been particularly effective at bringing sustainability issues to the fore in the design process. In the year when the project lead had not taken the course, sustainability also received less emphasis.

As collaborative, peer-led, project-based work with a strong service component, EWB projects have great potential to produce exceptional educational results since all of these characteristics can lead to better learning outcomes[15]. The cross-cultural context may also facilitate transformative learning, in which students question their cultural assumptions enabling them to examine, readjust or modify their world view[16]. The social relevance and service components of EWB work can attract and help retain and motivate women and other under-represented groups in engineering. At UMaine, about 52% of the most active engineering student members have been women, whereas women make up only about 12.5% of the undergraduate population in the College of Engineering[17]. This is lower than the national enrollment of women (17.4%[18]), probably due to the very low numbers of women in the School of Engineering Technology.

At UMaine, EWB's potential benefits have been realized for some students, yet a fairly large number of others have joined and then left the group without really finding their place. The students who have been heavily involved have grown in many ways, ranging from improved professional communications and fundraising skills, broader networks in the professional community, better time-management skills, finding a sense of purpose and motivation, developing a broader world view, and of course, improved design, problem solving and in some cases, practical/physical skills. Of course this evolution occurs over time and some change is attributable to the normal development of students as they progress through a degree program, but EWB does provide students with opportunities to interact closely with professionals and develop their skills while working on a "real" project.

Where EWB perhaps fails to live up to its potential appears to be for students who either come to it too early or ill-prepared to work independently. As a club, all of the work involved is, of course, voluntary and people enter at different levels of personal awareness and development, skill at independent study, motivation and technical competence. Given the complexity of working in an international arena on an open-ended problem, developing an appropriate solution is a significant challenge. The magnitude of the challenge sometimes overcomes students' motivation to do the work and/or their personal connections and feelings of responsibility to the group and partner community. Since the organization is run by students, the format has been very informal, with little support for the development of skills, no "required" or common readings (other than synopses of the project) or shared reflection on progress and what has been learned, except among executive members. These deficiencies are among those identified as reasons why problem based learning and service learning projects sometimes fail to meet expected educational objectives[15]. Guidance and educational materials have been produced but are often ignored or lost in a haphazard filing system over time. Individuals need different kinds of help to come up to speed and become active and competent team members, and the students often don't know how to provide the right kinds of support for one another. With deadlines in both school and EWB, there is a constant danger of burn-out and a slow loss of members from the group.

Participation in the Sustainable Solutions course has provided some common awareness and additional motivation to help the EWB project succeed, as well as modeling a way to reflect on the process and experience. Students who have worked on an aspect of the EWB project as a part of their capstone projects have benefited tremendously from the access to feedback from professors and other mentors. Deadlines to get things done and the requirement for written descriptions of the design rationale and approach, which promotes reflection, also served to reinforce lessons learned and how design elements contribute to sustainability. The capstone reports have been used as the basis for EWB paperwork, fundraising and training materials. The academic activities have reinforced the positive aspects of the EWB project for participating students by providing some form of supporting structure and accountability for getting the work done, and the outputs have been improved by the motivation of the students to perform for EWB's partner community.

Conclusions

To meet the considerable challenges that we face in the coming decades, engineers will have to consider the elements of sustainability in a more concentrated and deliberate manner. This will mean directing creative power in new directions. To support this change, the connections between sustainability and engineering practice should be explicitly incorporated into the curriculum. In environmental engineering, ecological sustainability issues fit well with technical content, so modifying courses to emphasize this side of sustainability, typically by taking a broader view of problem identification and system boundaries as well as a longer term view, is fairly straightforward. EWB is another avenue through which the need to consider longer term goals and human behaviors and aspirations in design is emphasized. As a student club, the educational potential of projects can be somewhat hampered by a lack of support structures, however, and students can fail to recognize some important connections. A non-technical course on sustainability in the global development context has provided some structure and an opportunity for EWB members to reflect on their experience and the design process. Since the course is not required, this remains an imperfect solution to the difficulties with the EWB model as an avenue to learn about and explore what it means to move toward a more sustainable society. Incorporation of some elements of project design into capstone projects has had benefits for participating students and improved the quality of the design produced by the EWB chapter.

Bibliography

1. National Academy of Engineering. 2008. Grand Challenges of Engineering. Obtained from http://www.engineeringchallenges.org/?ID=11574

2. ABET. 2009. Criteria for Accrediting Engineering Programs. Obtained from http://www.abet.org/Linked/Documents-UPDATE/Criteria and PP/E001 10-11 EAC Criteria 1-27-10.pdf

3. World Commission on Environment and Development. 1987. Our Common Future. Oxford University Press.

4. Rockström, J., W. Steffen, K. Noone, Å. Persson, F.S. Chapin, E.F. Lambin, T.M. Lenton, M. Scheffer, C. Folke, H.J. Schellnhuber, B. Nykvist, C.A. deWit, T. Hughes, S. van der Leeuw, H. Rodhe, S. Sörlin, P.K. Snyder, R. Constanza, U. Svedin, M. Falkenmark, L. Karlberg, R.W. Corell, V.J. Fabry, J. Hansen, B. Walker, D. Liverman, K. Richardson, P. Crutzen, J.A. Foley. 2009. A safe operating space for humanity. *Nature* 261(24 September), 472-475.

5. Mihelcic, J.R., J.B. Zimmerman. 2010. Environmental Engineering: Fundamentals, Sustainability, Design. John Wiley and Sons.

6. PBS. 2006. Design/e^2. PBS Home Video, Kontentreal.

7. L.D. Fink. 2003. Creating Significant Learning Experiences: An Integrated Approach to Designing College Courses. Jossey-Bass.

8. Felder, R.M. 1993. Reaching the second tier – learning and teaching styles in college science education. *Journal of College Science Teaching* 23(5), 286-290.

9. Norton, G.W., J. Alwang, W.A. Masters. 2010. Economic sustainability: Economics of Agricultural Development, 2nd edition, Routledge, chapters 1, Dimensions of world food and development problems, and 5, Economic transformation and growth.

10. Kofinas, G.P., F.S. Chapin.2009. Sustaining livelihoods and human well-being during social–ecological change Chapter 3 in *Principles of Ecosystem Stewardship*, Chapin, F.S. G.P. Kofinas, C. Folke (eds.), DOI 10.1007/978-0-387-73033-2 1, © Springer Science+Business Media, LLC

11. United Nations. Millennium Development Goals Indicators. http://mdgs.un.org/unsd/mdg/Default.aspx

12. McConville, J.R., J.R. Mihelcic. 2007. Adapting life cycle thinking tools to evaluate project sustainability in international water and sanitation development work. Environ. Eng. Sci 24(7), 937-948.

13. Reed, B., I. Smout. 2005. Building with the Community: Engineering projects to meet the needs of both men and women. Water, Engineering and Development Center, Loughborough University.

14. Peace Corps. "Culture Matters" The Peace Corps Cross Cultural Workbook obtained from http://www.peacecorps.gov/wws/publications/culture/

15. McKeachie, W.J. 1999. McKeachie's Teaching Tips: Strategies, Research, and Theory for College and University Teachers, 10th Edition. Houghton Mifflin.

16. P. Cranton. 2006. Understanding and Promoting Transformative Learning – a Guide for Educators of Adults, 2nd edition. John Wiley and Sons.

17. University of Maine office of Institutional Studies. Obtained 1/13/2011 at http://www.umaine.edu/ois/fact_book/enrollment/eng/eng10.htm

18. National Science Foundation. 2009. Women, Minorities and Persons with Disabilities. Obtained 1/13/2011 at http://www.nsf.gov/statistics/wmpd/pdf/nsf09305.pdf