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# Developing Sustainability Indicators for a University Campus*

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*This paper reports on a course that utilized problem-based learning in order to engage engineering students to develop indicators of campus sustainability. The course structure and project are evaluated against the attributes of intellectual development and learning approaches and the problem-based learning method. In addition, the degree to which students addressed the importance of balance and integration of societal, environmental and economic considerations is evaluated. A secondary intent is to offer an adaptable framework to aid other universities in developing a set of sustainability indicators. Results showed the multidimensionality of the selected indicators.*

**Keywords:** sustainable development; sustainability; indicator; university; problem based learning

## INTRODUCTION

TODAY'S ENGINEERS are faced with elevated constraints placed upon resource use and development due to an increasing global population. Such a challenge requires engineers to be able to design more environmentally benign and socially beneficial systems and technologies, find solutions even when substantial uncertainty is present and understand the social, environmental and economic effects caused by engineering decisions with respect to local, national and global communities [1, 2]. For engineers to provide leadership and vision towards a more sustainable future, they need to acquire additional higher-education skills that incorporate information from economics and the environmental and social sciences to engineering [2].

This is the second part of a two-article series. Part 1 [3] addressed cultivating intellectual development and integrating sustainability into engineering curricula. Problem-based learning is an accepted instructional method that uses student-centred environments to facilitate intellectual development and shows promise for incorporating sustainability concepts into engineering curricula. Sustainability, though vast and complex, seems to be the direction that humankind must take in order to continue its existence [4, 5]. Integrating sustainability ideals into engineering curricula requires students and instructors to embark on a new way of thinking, which indirectly signifies a new way of learning.

This paper reports on a course case study that utilized problem-based learning to integrate sustainability into higher education. The course had a class project with the objective of developing indicators of campus sustainability. Here, the course structure and its project are evaluated against the attributes of intellectual development and learning approaches, the problem-based learning instructional method, and the degree to which sustainability was incorporated. A secondary intent of this paper is to offer an adaptable framework to aid other university campuses in developing a tailored set of sustainability indicators and integrating management of the indicators into an academic engineering curriculum.

The benefits of engineering (and other) students developing campus sustainability indicators are unsurpassed. Engineering students can apply their analytical strengths to quantify data and improve upon inherent weaknesses in the qualitative assessment of social attributes. Additionally, this type of complex, ill-defined problem requires students to research the literature, brainstorm relevant indicators, seek feedback, collect data and measure progress towards a more sustainable campus environment. This process encourages intellectual development and builds creative-thinking skills.

Such a project also clearly develops the skills, knowledge and behaviour required of graduates of US accredited engineering programmes. Related to

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this project, engineering graduates from accredited US universities must demonstrate:

1) the ability to function on multidisciplinary teams;
2) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context;
3) knowledge of contemporary issues;
4) 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* (the language in italics was added for the 2005–2006 accreditation cycle).

## EVOLVING ENGINEERING EDUCATION IN THE 21ST CENTURY

'I hear and I forget. I see and I remember. I do and I understand.' (Confucius 551–479 BC). Many believe that today's engineer enters the workforce without the proper critical-thinking and creative problem-solving skills required to manage current sustainability issues and those sure to emerge in the future [6, 7]. Accordingly, engineering curricula must place a greater importance on acquiring such skills to confront large, interrelated problems, and less value on memorization of facts and comprehension of procedures. Incorporating sustainability principles and methods into engineering curricula thus demands a shift in the approach utilized in higher education, requiring a new horizon of possibilities and an evolution in how engineers think.

Part 1 of this series [3] discussed how problem-based learning could be used to promote student learning about principles of sustainability. To summarize briefly, intellectual development identifies characteristics of students as they progress through many levels of intellectual development, starting from dualism, to multiplicity subordinate, to multiplicity, and finally to contextual relativism [8]. In order to integrate the complex issues of sustainability into all engineering analyses, classroom environments should be designed to encourage constructive knowledge through critical thinking and contextual relativism. In student-centred environments, students take responsibility for their own education, while the instructor solely guides that learning process [9]. In other words, less reliance is placed upon the instructor to provide all the answers to students' questions.

A widely accepted instructional method is problem-based learning (PBL), in which critical-thinking skills are developed through solving complex, ill-defined problems [10]. PBL is an effective tool to stimulate learning in positive student-centred environments. For sustainability to be effectively integrated into engineering education, such a curriculum must transform the very basis of its operation (policies, assessment, courses, instructor knowledge, etc.), not just adapt sustainability ideals to fit any existing curricula structure [11]. A campus-oriented course such as this can serve to assist this transformation.

*Case study*

The linkages highlighted among intellectual development, problem-based learning and integration of sustainability addressed in Part 1 [3] are best exemplified through a case study of a specific course with a multidisciplinary class project. Five civil and environmental engineering graduate students enrolled in an elective graduate-level social science course 'Developing Indicators of Sustainability' in autumn 2004. The course was also open to senior-level undergraduate students. For graduate students, the course can provide credit towards a new Graduate Certificate in Sustainability. The course was a natural outgrowth of the instructor's research on societal sustainability indicators for the Lake Superior Binational Programme and the State of the Lakes Ecosystem Conference [12, 13, 14].

*Course structure*

The objective of the course was to engage students to develop indicators of campus sustainability. Four initial course goals, presented by the instructor, were for students to:

1) become familiar with a variety of processes and tools developed to create sustainability indicators (and the organizations that developed them);
2) evaluate the range of sustainability indicator tools and techniques for suitability to a university campus;
3) work in small groups (2–3) on a portion of a class project;
4) weave the pieces of the class project into a coherent report for presentation to the campus community;

Students added two additional course goals to this list:

5) increase awareness of sustainability on campus;
6) have fun.

Traditional student assessment tools (e.g. exams) were minimized as all efforts were put toward the many facets of the project. However, assigned readings and follow-up discussions were based on a text describing development of sustainability indicators [15].

*Class project*

The students first determined that the required written report be a framework to develop, document and maintain the indicators. The framework was intended to be not only informative to a diverse campus audience with varying levels of interest, but also adaptable to the university's

Table 1. Organizations with activities in sustainability that were researched at the beginning of the Developing Indicators of Sustainability course.

| | |
|---|---|
| United Nations Department of Economic and Social Affairs, Division for Sustainable Development | US Interagency Working Group on Sustainable Development Indicators (SDI Group) |
| Coalition for Environmentally Responsible Economies (CERES) | Bureau of Economic Analysis, Department of Commerce |
| Organization for Economic Co-operation and Development | World Commission on Environment and Development |
| International Institute for Sustainable Development | Fordham Institute for Innovation in Social Policy |
| International Sustainability Indicators Network | Bellagio Forum for Sustainable Development |
| Calvert-Henderson Quality of Life Indicators | Genuine Progress Index for Atlantic Canada |
| United Nations Development Programme | Index of Sustainable Economic Welfare |
| Earth Charter Commission | Global Reporting Initiative |
| Global Footprint Network | Sustainability Institute |
| Gold and Green 2000 | Sustainable Measures |
| Redefining Progress | Earth Day Network |
| Best Foot Forward | The Natural Step |

future needs and interests. The report was to be continuously updated and used as a tool to measure progress toward campus sustainability. In other words, the students sought to develop a framework that is in itself sustainable.

## WHAT IS A SUSTAINABILITY INDICATOR?

A SI measures the progress toward achieving a goal of sustainability. Sustainability indicators should be multidimensional, considering environmental, social and economic facets [16]. The University Leaders for a Sustainable Future (ULSF) states that:

> Sustainability implies that the critical activities of a higher education institution are (at a minimum) ecologically sound, socially just and economically viable, and that they will continue to be so for future generations' [17].

The students attempted to select sustainability indicators that would be as multidimensional as possible. An example of a common one-dimensional indicator of economic progress is gross domestic product (GDP). Some argue that GDP not only is insufficient to be used as a sustainability indicator, but also is an inadequate economic indicator due to its use for purposes never intended by its originator.

As the International Institute for Sustainable Development describes [18]:

> Societies measure what they care about. Measurement helps decision-makers and the public define social goals, link them to clear objectives and targets, and assess progress toward meeting those targets. It provides an empirical and numerical basis for evaluating performance, for calculating the impact of our activities on the environment and society, and for connecting past and present activities to attain future goals. Measuring sustainable development, just as we currently measure economic production, makes it possible for social and environmental goals to become part of mainstream political and economic discourse.

*Development of sustainability indicators*

In addition to the textbook [15], many web-based resources aided research into the development of sustainability indicators. First, students investigated the major international participants in sustainable development. Students used the list of organizations from Table 1 to initiate such exploration. Several class sessions were devoted to discussing the sustainability initiatives of these individual groups.

Thereafter, the instructor guided the students to learn from other groups currently using indicators to measure sustainability. Each class member examined one to two indicator projects that have occurred or are ongoing in five cities or states, and three other universities. Table 2 provides key information about each of these case studies (along with a comparison to this study), which offered the class insight and guidance for the project. As a result of investigating university and community case studies on development of sustainability indicators, the following five common and successful elements of such a project were identified:

1) common vision;
2) public participation;
3) organized reporting format and effective performance measures;
4) role identification and stakeholder involvement;
5) focused sustainable indicators with reference to the bigger picture.

The class used both universities and communities for the initial case study review, because a campus environment functions much like a community. In addition, several non-profit and non-governmental organizations centred on sustainability utilize standard methodologies for developing indicators of sustainability. The following is the list of methodologies that the class examined in detail:

1) Global Reporting Initiative;
2) University Leaders for a Sustainable Future;

Table 2. Comparison of city, state and university case studies that were reviewed at the beginning of the course.

| | | | Primary Classification of SIs | | | | | | | | | | | | Relevance to Project | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Indicator Project | Time | No. of SIs | Society | Economy/Business | Environment | Community | Education | Resource Use | Wellness/Health | Population | Youth | Democracy/Governance | Energy and Air Pollution | Solid and Hazardous Waste | Public Participation | Report Organization | Performance Measures | Stakeholder Role Identification |
| Minnesota Milestones | 1991–present | 70 | ◆ | ◆ | ◆ | ◆ | | | | ◆ | ◆ | ◆ | | | ◆ | ◆ | | |
| Sustainable Calgary | 1991–present | 36 | | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | | | | | | ◆ | ◆ | ◆ | |
| Sustainable Seattle | 1991–present | 40 | | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | | | | ◆ | ◆ | ◆ | |
| Burlington Legacy | 1999–present | 30 | | ◆ | ◆ | ◆ | | | | | ◆ | ◆ | | | ◆ | ◆ | | ◆ |
| University of Wisconsin—Extension | 1994–1998 | 24 | | ◆ | ◆ | | ◆ | ◆ | | | | ◆ | | | | | ◆ | |
| University of Michigan | 2001–present | 50 | ◆ | ◆ | ◆ | | | | | | | | | | | | ◆ | |
| Michigan State University | 1999–present | 76 | ◆ | ◆ | ◆ | | | | | | | | | | | | ◆ | |
| University of Vermont | 1990–2000 | 12 | | | | | | ◆ | | | | | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ |
| Michigan Technological University | 2004 (this study) | 12 | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | ◆ | | | | ◆ | ◆ | | | | |

3) Assessing sustainable development by the International Institute of Sustainable Development;
4) Communities by choice;
5) Calvert Henderson Quality of Life Indicators;
6) Redefining Progress and Earth Day Network;
7) Neighbourhood *Sustainability Indicators Guidebook* by the Minnesota Office of Environmental Assistance;
8) The Natural Step.

From the above sample, it was clear that successful projects implemented relatively few, yet effective indicators, used a cyclical approach to managing the indicators and clarified any new or complicated language associated with each indicator. In reviewing methodologies, the importance of an organized reporting format was reinforced. Additionally, several of the organizations established principles for selecting SIs. The class valued this aspect of SI development methodology, but because of the time constraints of a one-semester course, chose not to draft a set of principles for the campus, preferring to focus directly on developing the indicators. That process was informed by the principles other groups had developed, however, among which there was considerable overlap.

Public participation plays a critical role in the development of campus sustainability practices. Given a small enough community, public participation proves advantageous when implemented from the onset of a SI project [19]. The success of an indicator project is much greater when the citizens affected by it have an understanding and vested interest in sustainability. Students realized this after their initial research; they utilized email, memos, roundtable discussions, and campus presentations to convey information and receive feedback on the class project from the campus community. Once the students received resources and guidance that facilitated their knowledge of both the concept of sustainability and methods by which to measure it, they began to investigate (and develop) indicators that suited the campus best, as described below.

*Selected sustainability indicators*

The course participants created twelve indicators to assess campus sustainability. Table 3 contains detailed information on each SI, which consists of a goal, indicator, measure and target.

The goal provides motivation for the indicator's existence. The indicator identifies how progress toward the goal will be evaluated, whereas the measure specifies the data attribute(s) to track. The target defines the most sustainable level of the measure that the campus can reasonably reach.

The sustainability indicators behave cyclically as each of the aforementioned parts feed into the next with increasing detail. That is, the goal feeds into the indicator, to the measure, and then to the target. This circular logic was devised through the evolution of one-dimensional categories into multidimensional indicators [15]. Initially, more than a dozen general categories were identified (e.g. water, air, waste, economy, etc.). Then, long lists of factors were brainstormed under each category pertaining to social, environmental, or economic dimensions (i.e. one-dimensional factors). From these lists, it was apparent which general categories were interrelated to the degree that they should be combined, and which single-dimension 'contributing factors' could be paired (e.g. social and environment, economy and environment, social and economy) to create an indicator closer to what is considered a truly multidimensional SI.

Developing a set of SIs typically takes one to two years or more. Having less than four months, the students chose to draft a 'complete' set of indicators to initiate broad discussion rather than attempting to fully develop only one or two. Their hope was that the indicators would continue to evolve in subsequent courses or through the efforts of a campus group. Sustainability indicators on a university campus are viewed as a 'living' project: as the university grows and changes, so should the indicators. This attribute of indicators makes the course project ideal for continuing years. At the close of the project, each sustainability indicator was at a different developmental stage and may be improved upon well into the future (including addition or subtraction of an entire indicator).

An earlier draft of the twelve indicators listed in Table 3 was presented to a group of educators, researchers and staff affiliated with the university's Sustainable Futures Institute and the Environmental Sustainability Committee. Later presentations were made to the campus community via seminars and a meeting with the University Board of Control. An extensive amount of feedback was thus incorporated into the final twelve selected sustainability indicators, as well as into the required written report.

Also provided through feedback was a suggestion to illustrate the interrelatedness of each indicator to emphasize the multidimensionality of sustainability. Figure 1 shows the twelve sustainability indicators placed on a triangle based upon how well each measures a dimension of sustainability, these being environmental societal, and economic corners of the sustainability triangle. We have discussed in the past the components of this sustainability triangle, what we refer to as the basis for the sustainable futures model [2, 20]. In Figure 1, indicators grouped near the centre, such as material flow (SI #12), represent a good balance of the sustainable futures model, whereas those indicators close to a corner (e.g. SI #6, SI #8) or side (e.g. SI #4) characterize a greater influence of only one or two of the dimensions of sustainability, respectively.

An initial goal of the project was to develop multidimensional SIs, meaning that each indicator would relate to economic, environmental, and social sustainability of a university. The scatter of indicators away from the three corners of the sustainability triangle in Figure 1 shows the multidimensionality of those selected. This suggests that students were learning about the importance of balance and integration of social, environmental and economic considerations when solving a sustainability problem.

The level of solid, hazardous and radioactive waste as an indicator of material flow (SI #12) is an example of taking all three dimensions of sustainability into consideration. The amounts of waste themselves and fluctuations in those amounts are clearly an indicator of the campus environmental health. The influence of green purchasing on waste generation also evaluates campus economic policies. Furthermore, the success of recycling efforts and pollution prevention strategies are indicative of the commitment across campus. Hence, SI #12 is an example of an indicator with the multidimensional nature expected of sustainability indicators. Some other indicators happen to be heavily focused on only one dimension with little influence from the others. For instance, a balanced budget for the university is a good indicator of its economic health, but offers little information about the environmental or social sustainability of the campus community.

The meaning of the indicators' proximities to the centre of the triangle, and thus their 'dimensional balance', has been the topic of some debate. Initially, class members felt that an indicator's centrality was a measure of its maturity as a SI. In subsequent discussions, however, class members believed that having a few single-dimension indicators in each of the three areas was a beneficial feature of the set. If changes on campus favour or slight one dimension in comparison to the others, a set of highly multidimensional indicators might show progress or retreat from the goal of striving for a more sustainable campus. This condition is clearly illustrated by the heavy focus on economic development of today's world at the expense of the environment. Possible solutions to this potential issue include:

1) creating separate sets of single-dimension 'base indicators' and multidimensional sustainability indicators;
2) developing two separate indicators for each category, one as a base indicator and a second as a multidimensional sustainability indicator;
3) simply continuing with the presently developed indicators.

Table 3. Detailed sustainability indicators of the class project. Each SI consists of a goal, indicator, measure and target. The goal provides motivation for the indicator's existence. The indicator identifies how progress toward the goal will be evaluated, whereas the measure specifies the data attribute(s) to track. The target defines the most sustainable level of the measure that the campus can reasonably and feasibly reach.

| Category | Goal | Indicator | Measure | Target |
|---|---|---|---|---|
| Economic Health of Students | The expense of students' education is a good value with respect to their earning potential | Determine how economically feasible the cost of a degree is for a student independent of the student's financial background | Average net cost (tuition + fees + living expenses—financial aid—wages) of education / average 4-year starting salary | The above measured ratio is at least comparable to the ratios for other benchmark universities |
| Economic Health of Professional Staff & Faculty | Working at the university provides faculty & professional staff with a good standard of living | Determine how economically feasible working at the university is for a faculty / professional staff member relative to cost of living | Mean/median faculty & professional staff salary & fringe benefits / cost of living | The above measured ratio is at least comparable to the ratios for other universities |
| Economic Health of Staff (not included above) | Working at the university provides staff not included above with a good standard of living | Determine how economically feasible working at the university is for a staff member (not included above) relative to cost of living | Mean/median staff salary & fringe benefits / cost of living | The above measured ratio is at least comparable to the ratios for other jobs in local community |
| Economic Health of University | The university operates with a balanced budget (long term) and positive investment in both tangible and intangible assets | Determine the economic health (vitality) of the university as an institution relative to short term budget, long term net worth, and social capital | (Investments—depreciation) / total value of tangible and intangible assets | To be defined once measure definition is complete |
| Quality of Education | The university provides a quality education to students and strives to ensure their academic success | Determine the quality of the education offered by the university | Academic and overall scores from *U.S. News and World Report* on America's Best Colleges<br>Success of students, faculty, and alumni—difficult to measure; ideas include:<br>• job placement rate<br>• research / research funding<br>• alumni giving | To rank among the top X% of universities according to *U.S. News & World Report*<br>Student, faculty, and alumni success goals include:<br>• 100% job placement for students<br>• All research projects and grad students fully funded<br>• Alumni giving meets or exceeds budgetary needs |
| Water Use | Water consumption is optimized by conservation technologies and practices as measured by related economics (technology cost vs. payback) | Determine annual water consumption, conservation techniques, and related policies | Per capita consumption and cost of water | The combined cost of water usage and conservation techniques is minimized |
| Water Quality | Water pollution is minimized | Determine levels of criteria water pollutants (list pollutants here) in wastewater treatment effluent | Discharge concentrations of criteria water pollutants | Zero discharge of criteria pollutants as measured by best available technology (BAT) |
| Material Flow | University employs the following practices in management of its material flow:<br>• 'Green' purchasing to ensure responsible consumption of resources<br>• pollution prevention strategies to minimize solid, hazardous, and radioactive waste<br>• maximization of waste recovery (e.g. recycling, composting, etc). | Determine levels of solid, hazardous, and radioactive waste | Annual per capita waste generation and breakout by type (paper, glass, aluminium, plastics, hazardous, radioactive) and destination | Short term target:<br>• Materials are obtained according to established green purchasing guidelines<br>• 100% purchasing of recycled paper<br>• Full composting of organics and recycling of appropriate materials as economically and environmentally feasible.<br>• All hazardous and radioactive waste is properly managed.<br>Long term target: 0 waste |
| Community and Equity | University provides an environment and services that meet the needs of all faculty, staff, and students. | Perception of university's environment and services | Qualitative survey done by external auditor | University implements action items based on suggestions from previous survey |
| Energy and Air Quality | University's energy usage and air pollution are minimized per unit of activity. | Determine total energy consumption and contribution to air pollution | Total and per capita energy use, associated distribution of sources (renewables vs. non-renewables), and air emissions | University operates on 100% renewable energy |
| Transportation | University supports and promotes a variety of affordable and accessible transportation options with low environmental impacts | Quantitatively determine the cost and environmental impact of transportation alternatives and qualitatively assess their accessibility. | Qualitative accessibility survey done by Indicators class and university census data for campus commuting on:<br>• aggregate commuter miles per year<br>• % of population that travels via alternative options for each of the following: walk, bike, single driver car, carpooling, public transportation, telecommuting | 100% participation in usage of alternative transportation services |
| Buildings and Spaces | The facilities of the university provide an environment of learning and social interaction in accordance with the university's vision, considering environ-mental and economic factors | Quantitatively determine the cost and environmental impact of building modifications | Using Leadership in Energy and Environmental Design (LEED) criteria as a guide, assess each building and infrastructure modification on the university campus considering economic factors and function | All new buildings are LEED-certified silver or higher and all existing buildings are LEED-EB certified |

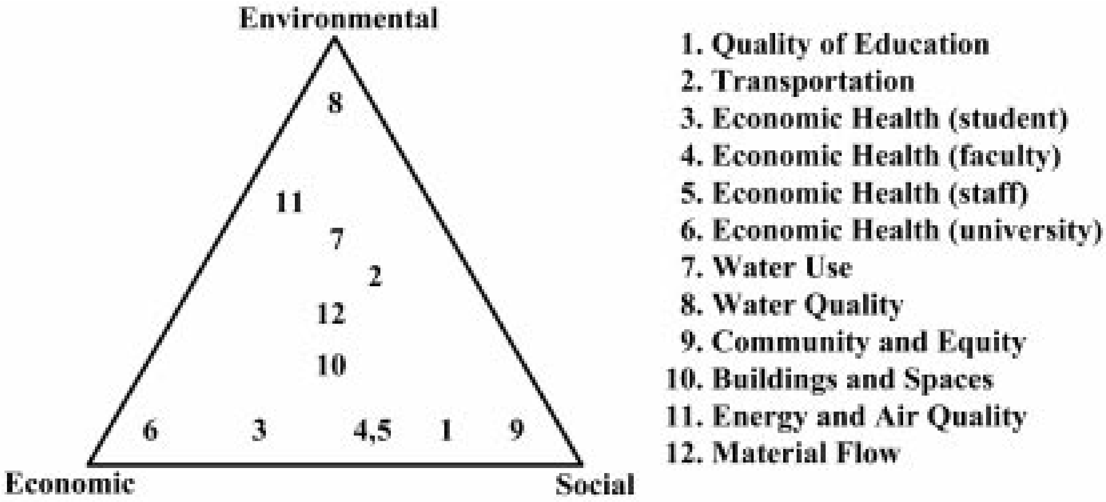


Fig. 1. Sustainability indicator triangle. The twelve SIs are placed according to how well each measures a dimension of sustainability, i.e. environmental, societal and economic.

The current set of indicators contains a mix of indicators addressing one, two and three dimensions. Though the coverage is not perfectly uniform, it does address all three dimensions singly and as a group.

*Lessons learned*

Throughout the course, the students learned that the complexity of indicator selection requires much time and dedication. Stakeholder participation in the development of SIs is crucial in order to gain acceptance of the indicators and to continue their maintenance into the future. Implementation of SIs across campus requires initiating interest and action from the 'top' and 'bottom'. Campus administrators must endorse the importance and use of the indicators, while students, faculty and staff must generate data through the efforts of courses, organizations and committees. Feedback should be continually sought and included, and is an important motivator in the indicator development cycle. Feedback gauges how the indicators affect the community, assesses their effectiveness and quality and offers guidance for their evolution. For indicators to be truly multidimensional, environmental, economic and societal goals must be weighted equally; the power of sustainability is in this balance of the three dimensions. An underlying thread to the entire course and class project was the students' desire to have fun. Making discussions and assignments enjoyable appeared to have encouraged steady progress on the project.

*Course assessment*

The results of the course post-assessment by students are shown in Table 4. Though the sample size is small (n=5), the students' indirect assessment of the course was very positive. The lowest evaluation score was received for the question related to whether the course organization helped the student to learn. This suggests that the instructor may want to provide more guidance in the future. In problem-based learning, with its student-centred approach, the instructor is challenged with finding that delicate balance of offering enough guidance without revealing all the answers. In review of written suggestions, several students did request a greater number of small, written assignments and incorporation of the course textbook into the class meetings earlier in the course (read entire text at an accelerated pace prior to starting project). These items suggest that some students wished in some fashion for a more traditional instructional method. It is uncertain if this is due to the students' comfort level with such a learning style, or whether they were dissatisfied with the level of self-direction often required in problem-based learning environments. This comfort level issue has been noted to pose a challenge with intellectual development and a difficulty in self-directed learning [21].

Table 4. Results of a student post-assessment of the Developing Indicators of Sustainability course. Students were asked to rate the question on a 5-point scale; 5 = strongly agree, 1 = strongly disagree.

| Class Average | Assessment Topic |
|---|---|
| 4.8 | The student wanted to take the course. |
| 5.0 | The class sessions were thought-provoking. |
| 4.2 | The organization of the course helped the student to learn. |
| 5.0 | The student is more interested in the subject now than before taking the class. |

Additionally, course features that students appreciated were:

1) flexibility and ability of the class to set the goals and timeline and to revisit/revise them;
2) the instructor's role as a resource;

3) presentations to, and feedback from, various groups outside class;
4) active group discussions and self-assignments.

All of these course features are prerequisites for a positive student-centred learning environment [3].

The course was designed to combine theoretical and practical elements by first researching efforts to establish economic, environmental, and social sustainability indicators at scales ranging from the campus, to neighbourhood, to global level. Similarly, the textbook applies a theoretical framework to a case study in Malta, which resulted in further revision to the authors' indicator development model for subsequent testing [15].

Underlying this approach was the conviction that greater value would be derived from having students focus on the process for developing indicators, based on their evaluation of a variety of case studies and methodologies, than to simply follow a 'recipe' from the instructor. Few courses catch the particular attention of the university administration, but this one resulted in a presentation made to the University Board of Control. Interestingly, a subsequent sustainability-related course, in which students performed preliminary energy audits of several campus buildings and auxiliary operations, had the president and two vice presidents in attendance during the final presentation of results. This trend in high-level interest can only be seen as positive for campus sustainability.

## EVALUATION OF THE CASE STUDY

There are several ways in which the case study promoted intellectual development, invited a deep approach to learning through problem-based learning and integrated sustainability into higher education. This section explores its successes and shortfalls in relation to these elements that were discussed in greater detail in Part 1 [3].

*Intellectual development*

Engineering students are rarely provided with the opportunity to expand their academic boundaries and support intellectual development. For years schools of engineering have taken a behaviourist approach to education. The traditional method of three lectures per week, three homework problems per lecture and three tests per semester is objective and limits engineering solutions to right and wrong answers facilitated by 'number crunching'. This behaviourist education model leads to the traditional teacher-centred lectures characterized by professors scribing notes and talking to blackboards while students rush to keep up in their notebooks. This manner of learning is one-sided and void of discussion, independent thought and social interaction [22]. For engineers to have the capacity to solve the complex, vast issues of sustainability, higher-education institutions should be enacting practices that cultivate high-level intellectual development.

In contrast to many traditional engineering courses, the Developing Indicators of Sustainability course offered a learner-centred environment that appears to have furthered intellectual development. All class members were graduate students expected to strive for high intellectual development. However, it was the first semester of graduate school for the majority of the class, so they were probably at a similar level of intellectual development. Throughout the course, and especially by the end, students exhibited attributes of high intellectual development described in Part 1 [3].

Students in the class immediately realized the contextual nature of SIs and utilized a wide variety of resources to individually and collectively construct a knowledge base on the topic. Students not only questioned the many indicator project case studies and methodologies they were provided with (Tables 1 and 2), but sought feedback from various stakeholders affected by the indicators (i.e. the campus community). The students also were confronted with ambiguity and uncertainty throughout the indicator development process. Many times indicator methodologies, attributes of indicator project case studies, and feedback obtained from presentation audiences contradicted one another, and students were required to assess all the information gathered to decide upon the best way to progress.

For example, while the students liked the University of Vermont's reporting format, indicator trend symbols, and small number of indicators (12 total), they noted that only the environmental dimension was considered. At the other extreme, Michigan State University's (MSU) set of 76 indicators covered the social, economic and environmental dimensions comprehensively. However, the students felt that many of MSU's indicators were simply traditional measures that could have been combined to make them more meaningful, multidimensional and easier for the campus community to grasp. As a compromise between these two approaches, some Michigan Tech SIs include multiple measures and lists of 'contributing factors' that address some of the inherently complex issues while maintaining a manageable number of indicators.

*Approach to learning*

The learner-centred environment of the course appeared to have encouraged creative-thinking skills throughout the semester. The course also offered various modes of learning (e.g. multimedia presentations, research, report writing, etc.). The instructor was proficient at communicating course expectations regularly (not just once at the start of the semester via the syllabus) and offering feedback on all tasks regardless of their size. It is hoped that the focus of the course on sustainability promoted the deep approach to learning which is believed to occur more easily when a topic is new and interesting [3].

*Problem-based learning*

This course offered students a new and exciting opportunity to develop critical-thinking skills by solving a complex, ill-defined problem: creating sustainability indicators for a campus. The instructor's own experience researching SIs for a multi-state region provided ample evidence that there are no universally accepted 'right' or 'wrong' indicators. Therefore, she focused on guiding the students to the best resources for making their own decisions instead of presuming to lead them to 'the answers'. However, students also suggested in the post-course evaluation some additional course organization.

This course met many of the essential elements of PBL discussed in Part 1 [3]. For example, the third essential element is 'problems must be multidisciplinary' and the eighth element is that 'problems must have value in the real world'. These two elements were addressed by several attributes of the course, but SIs are intrinsically multidisciplinary because they require students to consider social, economic, environmental and community factors. In addition, developing them for a campus certainly has real-world implications, as it is essentially a group of stakeholders making a commitment to progress toward a more sustainable campus environment.

Element five of PBL is that 'students must constantly reanalyse problems as individuals and as a group'. Developing and maintaining sustainability indicators involves a repetition of the following steps: broad research, analysis, feedback, narrow research and reanalysis; therefore, the course incorporated element five simply by the nature of indicator development.

Element seven of PBL is that 'students must take part in self- and peer assessment. This element was addressed not only by the 'lessons learned' activity, but also consistently throughout the semester due to the openness of class members. The instructor observed that students were never shy to admit a deficiency in work or compliment one another on excellent teamwork. The only essential element of PBL not achieved through this single course was element ten, which is 'PBL must be rooted in the curriculum, not episodic'.

## INTEGRATION OF SUSTAINABILITY INTO HIGHER EDUCATION

This case study appears to demonstrate the highest (very strong) of the four response levels of integrating sustainability into higher education that were discussed in Part 1 [3] because of its potentially large campus impact. In addition, the course can be used as part of the requirements for a recently initiated 15-credit Graduate Certificate in Sustainability that allows students to obtain curricular breadth in societal, industrial and environmental systems while also requiring depth in sustainability that can focus on the developing or developed world. The Graduate Certificate (and a proposed undergraduate minor) has also been integrated into several undergraduate and graduate engineering programmes that allow students to engineer solutions to challenges faced in the developing world as part of their engineering degree (for more detail on these educational initiatives, see [23]).

## INTEGRATION OF SUSTAINABILITY INTO ENGINEERING PRACTICE

A project of this type clearly fits skills, knowledge and behaviour required of graduates from US accredited engineering programmes, including:

1) the ability to function on multidisciplinary teams;
2) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental and societal context;
3) knowledge of contemporary issues;
4) 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.

The approach utilized in this project also demonstrates to students how to incorporate social analysis into an engineering design. Thus, upon becoming professional engineers, students will be capable of solving emerging problems through designs that are more socially relevant and environmentally benign, and as a result, more sustainable. Only technology that has been scrutinized socially, as well as technically, should be adopted for current and future generations.

## CONCLUSION

This paper reported on a course that utilized problem-based learning to engage engineering students to develop economic, societal and environmental indicators that measure campus sustainability. Several of the indicators selected were shown to be multidimensional. The course structure and project were evaluated against the attributes of intellectual development and learning approaches, the problem-based learning method and the degree to which sustainability was incorporated. An advantage of this type of course is that it can be readily adapted to any university and integrated into an engineering curriculum. The course also allows future classes to not only continue the process of developing indicators, but importantly, measure progress towards meeting targets of sustainability set by the campus community.

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