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Incorporation of sustainability concepts into a civil engineering curriculum

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Abstract

The need arises to equip engineering students with a wider horizon on concepts in terms of environmental, economic and social attributes, for decision making sensitive to sustainability issues. Pedagogic frameworks have to address a multidisciplinary analysis of sustainability. This paper addresses the rationale behind the recent integration of sustainability concepts into an undergraduate civil engineering curriculum in Hong Kong. Incentives and barriers for implementation of the curriculum are addressed. A team-based design project with problem-based learning approach is highlighted. The initial results of stakeholder evaluations suggested that multidisciplinary skills developed during the learning process might contribute significantly to pertinent knowledge on sustainability.

Keywords: Civil engineering; Engineering education; Evaluation; Sustainable development; Teamwork

Introduction

In recent decades, the enhanced public awareness of environmental degradation has prompted the shift of focus in the built environment from passive waste clean-up and pollution control to proactive pollution prevention and ecological sustainability (Painter 2003). The concept of cleaner production and sustainability came into focus after the issue of the Brundtland Report (Brundtland 1987). A broad definition of sustainability is to meet the needs of current generations without infringing upon the needs of future generations or compromising their abilities to maintain a similar standard of living with minimal environmental degradation (ASCE 2006; Institution of Civil Engineers 2006; The Hong Kong Institution of Engineers 2006). Lemkowitz et al. (1996) proposed that sustainability is intimately associated with safety, health and environment via the concept of spatial, temporal, biological and intellectual scales.

In order to ensure sustainability and ecosystem well-being, attention has to shift to acquiring more output from less resource, with less waste, and less damage to the environment. The

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main objective is to attain sustainable ecosystems that integrate human society with its natural environment for the benefit of both (Gutierrsz-Martin and Dahab 1998). There is a recent trend to integrate sustainability into different disciplines such as mining engineering (Costa and Scoble 2006), design (Vezzoli 2003), ecological engineering (Mitsch 1996), environmental engineering (Gunn 1996; Barger and Hall 1998; Bhamidimarri and Butler 1998), etc. The integration of sustainability into civil engineering is also desirable (Kibert 2005).

Civil engineers have a role to direct the greatest resources in nature for the best interest of mankind, in harmony with human aspirations and sustainable quality of the environment. They should devise feasible solutions that are affordable and in accord to aspirations of society, by contributing to economic growth, to environmental protection and to improved quality of life. In order to accomplish these objectives, solutions should strike an informed balance in terms of cost, benefits, sustainability and acceptability within the broader legislative framework, and involves the concepts of life cycle costs accounting for both the economic feasibility of engineering project and their long-term tangible and intangible environmental impacts.

There arise needs to incorporate sustainability concepts and principles in both professional practices and education in the field of civil engineering. As a first step, a paradigm shift of engineering education is necessary in order for humanity to realize the goal of sustainability. This paper presents efforts made to reorient civil engineering education to promote the concept of sustainability in an undergraduate curriculum in Hong Kong.

Incentives to implementation

Whilst civil engineers should all search for ways to enhance their environmental capabilities and to produce sustainable designs, emergence and development of more sustainability aware engineers would enhance their services to humankind and the rest of nature. The long-term goal will be more sustainability aware engineers infiltrating all engineering sub-disciplines and specializations. There is a pressing need to inspire and equip engineering students with the means to design and implement the required solutions incorporating sustainability concepts.

As such, university level education also entails a radical reorientation in order to enable a new generation of professionals to more effectively and positively confront the transition towards a sustainable society and act to influence it. The holistic approach comprises a wider knowledge base in the social, political, and life sciences in addition to physical sciences and

mathematics. It has to furnish students with the ability to analyze, comprehend and understand the multi-dimensional aspects of sustainable development problems. It is reckoned that the best way to prepare civil engineering students for future challenges is to furnish them with a fundamental education in basic sciences, engineering fields and society, as well as the linking amongst them in a broad manner. In this regard, three types of sustainability should be emphasized, namely, environmental, economic and social. Under the above background, this new pedagogical curricula with an overt sustainability emphasis for engineers began to be developed and implemented.

Barriers to implementation

The major barrier to changing the existing education structure comes from the inherent requirement of broad knowledge in sustainability issues. The work load of the existing curriculum is already very heavy and it appears in first sight very difficult to include increasing volumes of sustainability related materials. Increasing that content by the addition of new concepts will require the loss of other essential material. After all, this problem can be solved since, in implementing engineering education, technology trends should not be the focal point since they may soon be outdated. The focus should be on problem-solving, decision making with incomplete information, working in multi-disciplinary teams, practicing their presentation skills, and wider exposure to different topics throughout the program, which is in line with the recommendations of the ASCE Body of Knowledge Committee (ASCE 2006).

During the program revision stage, a fundamental problem encountered is the choice of a special module on sustainability or the integration of appropriate sustainability concepts into the existing modules. The feasibility of the incorporation of sustainability as an individual subject is in doubt. The latter strategy is adopted here owing to the better appreciation of the holistic nature of sustainability in real application cases in civil engineering field.

Strategies and pedagogy for sustainability

The emergence of sustainability as a concern within engineering has drastically changed the problem solving model conventionally employed by the profession. It is evident that pollution prevention is the primary engineering component to sustainability. Pollution prevention or source reduction is considered at the top of the environmental management hierarchy since pollution which is prevented will not entail the extra effort of treatment and disposal. Alternate design approaches should be adopted which would focus on the use of natural processes that work with the environment and without consuming excessive

additional resources in mitigating contamination problems.

In addition to context specific skills, they should acquire a more holistic perspective on sustainability, associated with the environment and its engagement with the needs and aspirations of society. The breadth of knowledge base entailed for effective sustainability development is increasing continuously.

It is believed that cross-disciplinary thinking and skills are key elements of sustainability relevant knowledge. The integration enables students to gain understandings of techniques, philosophies and knowledge from more than one discipline. Since civil engineers often need to work in interdisciplinary teams, this type of knowledge is paramount for them to manage the contributions of various socioeconomic as well as environmental factors to desired engineered solutions, and to engage in meaning and mutually informative dialogue with other pertinent stakeholders, such as architects, building services engineers, ecologists, electrical and mechanical engineers, landscape architects, town planners, etc.

This approach would lay the foundation for a thorough understanding of natural phenomena and their influences on environmental media. Since future problems to be solved by engineers are changing rapidly, in term of both new technological opportunities and socio-cultural conditions, undergraduate education should not be too narrow by focusing on specific practices and technologies.

Curriculum changes

The shift of the curricula are made in such a manner that sustainability themes are introduced in a generic manner and students are made aware of the significance of incorporating environmental influences/constraints in any design activity. Teaching and learning is tailored to furnish students with the chance to experience the pleasure and difficulties associated with interdisciplinary teams, as well as the discomfort of having to work with uncertainties. Work integrated education such as a practical industrial component is considered useful. Moreover, more room is furnished for open-ended problem solving and decisions making based on limited knowledge. Innovative solutions that require less expenditure of natural resources and energy and simultaneously work with the natural environment would be encouraged.

In the new curriculum, knowledge of environmental policies, ethics and concepts, law, management, industrial ecology, cleaner production, resource efficiency, life cycle assessment, design for environment, environmental impact assessment, etc. are added as new topics in different existing subjects. More focus is also placed on the understanding of the

overall paths taken in the ecosystem or life cycle assessment of the use of resources. More socio-economic and interdisciplinary contents are added as new topics into pertinent existing subjects such as Environmental Science (CSE203), Construction Management I (CSE303), Construction Materials (CSE 308), Economics and Law (AF3902), etc. Moreover, new topics like urban water recycling principles and sustainable urban drainage are introduced into the existing subject Drainage Engineering (CSE412). Another example is the addition of a new topic of sustainable sludge management in the subject Water and Waste Management (CSE406).

Problem-based learning (PBL)

The design project, which is based on problem-based learning (PBL), is an ideal opportunity for students to experience real-life problem solving, project management, interpersonal skills of written and verbal communication, working productively in a team, work integrated education and leadership skills. Teamwork, which by its nature promotes the multi-disciplinary aspect of solution techniques, is emphasized here. In order to help students grasp a perspective of what will be encountered in their first job, the involvement of guest lecturers from industry can be very useful.

One of the objectives of the project is to furnish students with an understanding of sustainability issues in relation to civil engineering industry and develop practical skills to support the application of sustainability principles to engineering design. A main emphasis is on cleaner production, and the crucial issues in practice are to translate these abstract paradigms into meaningful practical educational experiences that appeal to civil engineering students. Students have to make decisions on the most appropriate solution from knowledge gained during the taught modules, in consideration of sound engineering principles as well as sustainability concepts, which include awareness, institutional factors and normative-ethical aspects.

A specific example of the team-based design project is the design of a footbridge. In the design brief provided by the client, the students are required (i) to consider possible use of re-cycled materials in the choice of construction materials, (ii) to undertake a local ecological impact assessment of the project to ensure that the biodiversity will not be adversely affected, (iii) to ensure that the infrastructure will blend with the surrounding and be environmental friendly, (iv) to offer feasible engineering solutions and construction methods that will minimize waste as well as environmental pollution during the construction, operation and maintenance, and (v) to adopt appropriate general arrangement as well as cover material of bridge so as to maximize daylight and minimize energy consumption. Prior to the new

curriculum, no specific emphasis was placed on sustainability issues in running the team project.

Assessment and evaluation

In order to assess the effectiveness of the incorporation of sustainability dimension into the curriculum, in particular via a team-based design project with problem-based learning approach, the evaluation by its key stakeholders, which are students, preceptors and employers, is required. It comprises student feedback questionnaire, peer review, supervisors' comments and employer surveys.

Student Feedback Questionnaires

Analysis of student feedback evaluation forms suggests that the new course is performing well and has been successfully integrated into the existing curriculum. A questionnaire has been completed by a total 332 students before and after the design project for 3 years from year 2003 to 2005. The questionnaire explored student perceptions about learning effectiveness of the group project in terms of a multitude of factors covering attitude, motivation, interaction, problem solving, interdisciplinary learning, sustainability issues, innovation, team productivity, and so on. In this paper, only the sustainability issues are focused. Table 1 extract results of the student feedback questionnaire survey, which demonstrated the learning effectiveness of the open-ended PBL approach to inculcate knowledge on sustainability issues, as reflected by the higher ratings placed by students on the significance of sustainability issues after the project. Results of another three previous years prior to the implementation of the new course are also used as a yardstick. It can be observed that the curriculum changes have also positive impacts on reinforcing students' perceptions on the significance of sustainability issues.

Peer Review

All students were given opportunity to rate the performance of other design groups, which contributed to a certain proportion of the total marks for the project. In the marking sheet provided to individual students, one of the judging criteria is on sustainability issues. Their accomplishment of this goal was assessed and evaluated by their peers. This further strengthened their belief that sustainability issues are a very imperative factor.

Preceptors' Opinions

For the design project, preceptors comprise both academic supervisors from the Department and industrial supervisors who are practicing engineers currently working in the industry. The gauging of preceptors' comments was mainly employed to streamline the entire process

during the operation of the design project. In fact, many modifications have been implemented arising from experience gleaned in order to enhance fairness of the assessment and effectiveness of the exercise and to better implant sustainability concepts and understanding into the project. They include addition of a seminar on sustainability issues, re-scheduling of the site visit from week 7 to week 4, adjustments on the relative proportion of individual performance and group effort in the final assessment, the degree of involvement of practicing engineers from the industry, etc. After the incorporation of the comments made by the preceptors, the running of the design project was smoother in the second year of operation.

Employer Survey

The employer survey can serve as a good opportunity for our Department to be aware of the competitive edge of our graduates, via benchmarking with other academic peers. Their evaluations are considered to carry a very significant weight as they are the ones who ultimately employ the graduates. A questionnaire has been completed by a total 86 employers in 2004. The results in general revealed that graduates from the other universities in Hong Kong which also offer civil engineering degree program were more theoretical whilst our graduates had advantages in three distinct aspects: namely, wider horizons; more sustainability awareness; and, more innovative. It is noted that the curriculum of these peer departments are similar to that of ours, except the new curriculum on sustainability issues and the university-industry cooperated design project. This might be attributable to the wider exposure to socio-cultural and sustainability topics and the open-end PBL-based design project under the guidance of practicing industrial supervisors.

Conclusions

The recent awareness of environmental degradation prompted pressing concerns over the sustainability of the natural environment. Civil engineering is a key profession to the incorporation of sustainability into our society. There arise needs to equip civil engineering students with a wider horizon on concepts in terms of environmental, economic and social attributes, for decision making sensitive to sustainability issues. A new pedagogic frameworks addressing sustainability in a civil engineering curriculum in Hong Kong is adopted. A team-based design project incorporating sustainability dimension into the curriculum and problem-based learning approach is evaluated. The initial results of evaluations by graduates and their employers both suggested that multidisciplinary skills developed during the learning process might contribute to pertinent knowledge on sustainability. One may point out that it is insufficient to totally rely upon the use of PBL in capstone design activities to re-orient students and to instill a full understanding and practice

of sustainability throughout their career. As such, additional curriculum changes appear to be simultaneously needed to accomplish this significant modification to the traditional engineering problem-solving process. Nevertheless, the current approach provides a start on this.

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Table 1. Extraction of student feedback questionnaire surveys on their perceptions on the significance of various factors in construction projects

Factor	Average rating						
	Prior to project at year			After project at year			Mean of previous 3 years (2000-2002) before new course
	2003	2004	2005	2003	2004	2005	
Buildability	4.3	4.2	4.1	3.8	4.0	4.0	4.2
Cost	4.1	4.0	4.2	4.0	4.1	3.9	4.1
Time	3.8	3.7	3.9	3.6	3.5	3.7	3.8
Quality	3.2	3.4	3.5	3.4	3.6	3.2	3.0
Sustainability	2.6	2.4	2.5	3.2	3.1	3.3	2.2

* Ratings 1 to 5 indicate the relative importance of various factors in ascending order