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Training Engineering Students in Sustainable Development

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***Abstract*—**Work on sustainable developments and the call for action in education for sustainable development have been ongoing for a number of years. Training engineering students with the relevant competencies, particularly in sustainable development literacy, has been identified as an urgent task in universities. This requires not only a holistic, multi-disciplinary approach to education but also a suitable training environment to develop the needed skills and to inculcate the appropriate attitudes in students towards sustainable development. To demonstrate how this can be done, a module involving an overseas field trip was introduced in 2013 at the National University of Singapore. This paper provides details of the module and describes its training philosophy and methods. Measured against the student learning outcomes, stipulated by the Engineering Accreditation Board, the module scored well on all of them, particularly those related to complex problem solving, environmental and sustainability awareness, multi-disciplinary team work and varied-level communications.

***Keywords*—**Civil engineering education, student learning outcomes, sustainable development.

I. Introduction

THE concept of sustainability has been promoted in various quarters since the landmark Brundtland report [1] some 30 years ago. In calling for action and the setting up of an UN Program of Sustainable Development, the Brundtland Commission had identified that there would be a need for a "vast campaign of education, debate, and public participation" to adopt sustainable development. Since then, sustainability has been articulated in numerous high-level meetings, notably at the Rio Summit [2] in 1992, the Johannesburg Summit [3] in 2002, the Rio+20 Summit [4] in 2012 and more recently in New York [5]. Along with these high-level meetings, there has been numerous initiatives at global, regional and national levels addressing various issues related to sustainability, such climate change, global warming, renewable energy, and smart growth.

It was recognized at an early stage that to achieve the sustainability goals, education would be the key to success. Consequently, on the premise that "education is the way to shape the values, skills and knowledge required to build sustainable societies", the UN Decade of Education for Sustainable Development [6] was initiated in 2005 to encourage enhanced teaching and learning about sustainable development. Progress in education for sustainable development has been reported regularly at various international meetings, resulting in UN declarations, such as in Bonn [7] and in Nagoya [8]. At the end of the UN decade of action, the final report [9] noted that while there were some advancements in enabling structures and pedagogical innovations as well as broad levels of propagation of education for sustainable developments, much still needs to be done to raise the level of sustainability literacy in society. It also identified five areas of Global Action Plan involving (a) advancing policy; (b) integrating sustainability practices into the education and training environments; (c) increasing the capacity of educators and trainers; (d) empowering and mobilizing the youth and (e) encouraging local communities and municipal authorities to develop community-based education for sustainable development (ESD) programs. In a follow-up report [5], it was identified that tertiary education in sustainable development is likely to result in greater participation in the sustainable development agenda. Indeed, beyond promoting greater sustainability literacy generally, there are concerns whether graduates from higher education will possess the necessary attributes to be able to deal with the complex issues involved in sustainable development [10]. It is recognized that universities "need to be more proactive and aggressively infuse ethical and moral teaching and values into their curricula" [11]. This is, perhaps more relevant to engineering graduates who are more likely to be involved in creating, managing, operating and maintaining future developments that have to fulfil sustainability objectives. It is therefore not surprising that engineering programs in tertiary institutions are taking the lead to embrace the sustainability agenda [12], calling for a "new kind of engineer" to be trained in universities [13]. A number of handbooks, toolkits and guides, e.g., [14]-[17], have also been published to encourage the introduction of sustainable development into university curriculum. However, many have also expressed difficulties, citing issues such as overcrowding curriculum [18], lack of multi-disciplinary and trans-disciplinary faculty members [19], reluctance of students [20] and department and institutional barriers [21].

In tandem with these developments, the World Federation of Engineering Organizations, representing professional engineering associations around the world, has specifically highlighted the need for strong emphasis in having sustainable development programs in engineering education [22]. Having identified professional competencies for future graduates, the International Engineering Alliance, representing international agreements on accreditation of engineering programs, has also

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revised the student learning outcomes required in university engineering programs [23]. Inevitably, many of the student learning outcomes embrace aspects of training in sustainable developments.

At the National University of Singapore, the need and urgency to introduce sustainable development into the curriculum is no different from many universities around the world. Among the many similar obstacles faced, the biggest challenge is the lack of motivation among faculty members to adopt a more holistic approach to sustainable development. This is largely because in the research-oriented environment, faculty members are less motivated to step out of the specialized area to embrace an integrated broad-based approach to engineering education which is necessary for training in sustainable development. To overcome this inertia, the Civil and Environmental Engineering Department in 2013, introduced a module entitled "Socio-economically sustainable infrastructure development" into the curriculum to demonstrate how engineering students should be trained to be future ready and literate in sustainable development.

II. Module Structure

A. Module Description

The level-3 technical elective module is offered, though not restricted, to civil and environmental engineering students. It is designed to train students to develop practical understanding on sustainability issues by working on a real-life project with an overseas field trip to rural region in Yunnan, China. The technical deliverable of the module is a sustainable infrastructure development master plan of a village in Yunnan. The necessity for close supervision particularly during the field trip meant that the student number has to be limited to about 20.

In setting the proper learning environment, which is the focus on the field trip, the module is conducted in 3 stages: *Pre-trip preparation, Field trip execution* and *Post-trip reflection.*

B. Pre-Trip Preparation

At the preparatory stage, which lasts for 13 weeks, the students meet for instruction with research exercises on sustainable development issues related to the target village of the study. The mode of teaching involves lectures, self-directed learning, workshops and laboratory sessions in the setting of a real-life problem of developing a sustainable master plan for the target village. Lectures include topics on sustainable developments as well as the political and historical evolution of China and social changes in Chinese society. The latter topics, which are less technical in nature, help to orientate the students to think more holistically before embarking on any technical design. The students are also organized into small groups to do self-directed studies and interactive learning on the climatic, environmental, economic and cultural characteristics of Yunnan, particularly among the rural communities as well as current practices on land reforms and control in China. To encourage collaborative learning, they are to present these succinctly to the entire class. Several technical tools are also taught in a workshop style. Students are instructed on the techniques to conduct household interviews in the form of *Participatory Rural Appraisals (PRA)* as well as a group *Risk Assessment* exercise. At the same time, technical skills associated with computer-aided drawings, water-quality testing and soil sampling are acquired in practical laboratory sessions.

In view of the field trip, the class is organized as a field team with each student charged with specific responsibilities. Some are given management roles, such as *Team Leader, Program Coordinator, Treasurer, Crisis Manager, Logistics Manager, Communications Manager* and *Webmaster.* Others are given technical roles such as *PRA lead, Master planning lead, Water resource lead* and *Physical survey lead.* The students are matched to the most appropriate roles according to their personality and preferences.

To maximize the opportunities in the field trip, the team will have to carefully plan the trip activities, including all of the logistical requirements.

C. Field Trip Execution

During the second stage, the students accompanied by two professors, will spend two weeks in the designated village in Yunnan, China. In the first few days of orientation, the students will have a brief interaction with students from Yunnan University, to gain some understanding of life in China and the social norms of Chinese youths. They will also participate in some cultural exchange programs and visit a number of restructured villages to appreciate the different communal living conditions and rural settlement architecture and schemes. Before arriving at the target village, they will make a general tour of the region on vehicle as well as on foot to gain first-hand insights into the general topographical and environmental set up of the surrounds. A courtesy call on the township Mayor's office is also made, during which they will be briefed by officials on the planning strategies of the township which is responsible for the administration of the target village.

At the target village, the students will be divided into smaller groups to undertake a number of in-depth studies. First, the students will conduct a transect walk of the village settlement area as well as the wider village farming area, taking note of the terrain, vegetation and existing infrastructure. A physical survey team will map out the settlement area, recording details of buildings and structures, natural streams and man-made drains as well as other infrastructure on satellite maps which are prepared before the trip. Some ground levelling surveys are also conducted to add some elevation dimensions to the satellite maps. A visit to the village's source of water supply, which is several kilometers away in one of the mountain springs, is followed by the mapping of the water channels and pipelines from the source to the village storage tanks. Water quality measurements, including pH, turbidity and E. coli tests, are also conducted at several locations along the water supply route, to ascertain if there is any deterioration of the water quality.

One of the more important exercises is the *Participatory Rural Appraisal,* a household interview to gather information about the residents. The students will visit every household and hold informal discussions with the household members to understand their lifestyle and aspirations. Conducted in an engaging manner, these sessions are proved to be very useful in building relationships and trust between the students and the residents and in obtaining insights into the background, habits, customs, living conditions and even genealogical links of various households. It is from these discussions that students develop a deeper sense of the needs of the villagers.

At the end of each day, students will gather to share and summarize their work of the day in an interactive session. In particular, they will examine and compare the data, examining uncertainties, as well as the differences and errors of measurements. This is particularly needful in handling PRA data, which are qualitative, based on perception, and may be biased. It is not uncommon that students will have to do some retracing of their work in order to validate, correct or even supplement their data. The students will also have dialogue sessions with the village leaders, elders and representatives, who are able to see the progress of the surveys as the student findings are updated daily and presented visually in the form of photographs, charts, graphs, drawings in the communal area provided by the village as the student work place.

As the work progresses, the students spend the evenings putting together a comprehensive map or drawing of the existing infrastructure of the village. This will pave the way for generating a comprehensive master plan for the village which will be highly dependent on their assessment of the needs of the village as articulated by the different household representatives. In generating the draft master plan, the views of the village representatives are constantly sought to ensure that plans are well aligned with the aspirations of the villagers. Several alternative themes may be explored with the villagers to support the concept of sustainable developments. For example, the village may be redesigned to embrace an eco-tourism development concept or a rural resort development concept. The appropriate infrastructure components to be planned or redeveloped are then incorporated into the master plan.

The students need to consider the necessity for sustainability in terms of environmental, economic and social impacts and these have to be communicated in a simple manner to the villagers for their consideration. One particular tricky issue is the allocation of space for communal developments, such as tracks or roads, water storage facilities, waste disposal facilities as well as the creation of space clusters and pens for farm animal habitation. These have to be aligned with the peculiar legislative control of land leased to the residents from the state. The final deliverable to the village will be several variations of a draft sketch plan with infrastructure details, to be handed over formally to the village representatives. Villagers are able to visualize these plans from 3-D images and perspective views generated from computer-aided output produced by the students.

Besides the technical work at the village, the students also made several visits to engineering enterprises as well as land and infrastructure developers to understand the business environment in China.

D.Post-Trip Reflection

In the post-trip stage, the students will work on two components during the three weeks following the trip. First, the students will meet to consolidate the plans for the village. In finalizing the master plan, they may need to do further research into the technical feasibility and impact of each component of the master plan. This may warrant the study of specific technical manuals or best practices elsewhere. In so doing, the students need to ensure the proposed developments will preserve the cultural characteristics and heritage of the village. For example, the students have to address the impact on any redesigned or relocated buildings on individual household as well as the entire village community.

A detailed assessment of the environmental, economic and social impacts will be carried out. In particular, the nature, extent and severity of each issue will need to be quantified into impact weights or costs. Furthermore, a life-cycle sustainability assessment, a land-use balance sheet and Social Sustainability Evaluation Matrix are also comprehensively worked out.

Towards the end of this post-trip stage, the students will also meet to review their learning journey and experience and to document their individual reflections. In particular, they need to consider their learning in terms of the knowledge gained, skills acquired and values developed towards sustainable development. Looking forward, they are also to consider what steps they would take to further develop their interest in sustainability, particularly in relation to their career choice and advancement. As an immediate application on sharing their learning in sustainable developments, the students are required to produce a poster or a video to share with the wider student community on their learning experience, highlighting their exposure in sustainable development.

III. Student Learning Outcomes

In keeping with the agreement reached under the Washington Accord, the Engineering Accreditation Board in Singapore under the administration of the Institution of Engineers has stipulated 12 Student Learning Outcomes (SLO) for engineering education, similar to those listed by the International Engineering Alliance [23]. While these learning outcomes are normally evaluated at the program level, it is helpful also to evaluate them in this module to assess its contribution towards the entire engineering education. The evidence of achievement in these SLO are viewed from three perspectives: (1) components designed and embedded in the module for such learning and (2) assessment modes used to evaluate the competencies and (3) response rating of students on such learning upon completion of the module.

The learning opportunities offered in the module and the corresponding assessment modes that fulfil the various learning outcomes are summarized in Table I. The degree of contribution of the learning opportunities and assessment modes to achieve each of these SLO, as rated by the module facilitators are also appended to the Table. In an end-of-module survey, students are asked to rate how well they have achieved these student learning outcomes on a 10-point scale. The distribution of the rating scores is shown in Fig. 1 with the mean score appended in the last column of Table I.

TABLE I
EFFECTIVENESS OF TRAINING BASED ON STUDENT LEARNING OUTCOMES

Student Learning Outcomes [23]	**Learning Opportunities**	**FR** (Faculty Rating)	**Assessment Modes**	**FR** (Faculty Rating)	**SR** Student Rating (Average)
Engineering knowledge: Apply knowledge of mathematics, natural science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.	Use of mathematics and physics in land surveys, chemistry in water quality testing. Application of Sustainable Development principles and practice in context of rural master planning, encompassing various infrastructure engineering aspects, which are highly intertwined with social development.	High	Land survey maps, water quality test results and interpretation, proposed master plan of village.	High	7.5
Problem Analysis: Identify, formulate, research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.	Formulation of a proposed scheme of work to identify issues on sustainable development relevant to the study village. Research into scholarly writings related to specific elements of sustainable development as well as peculiar issues that constrained or influence solutions such as topography, climatic conditions and land legislation.	Very High	The problem statement governing the objective to generating the infrastructure master plan of the village	High	8.4
Design/development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for public health and safety, cultural, societal, and environmental considerations.	Generation of a master plan with various elements such as housing, water supply, waste disposal, energy usage and transportation taking into account human-animal segregation and pollution control for health and safety, retention of cultural heritage and rural lifestyle, access to healthcare and other amenities as well as impact on farming, social dislocation and induced visitor numbers to village.	Very High	A map of current land use of village with existing infrastructure elements and a proposed master plan that includes all relevant infrastructure elements with summaries of impacts and sustainability indices.	Very High	8.6
Investigation: Conduct investigations of complex problems using research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.	Design and management of land surveys, water quality tests, soil sampling and household surveys in the form of *Participatory Rural Appraisals*, including selection of essential and portable equipment and test kits. Effective presentation of results in the form of graphs, charts and tables after interactive sessions of triangulation, data verification, validation and interpretation.	Very High	Photographs, diagrams, charts and maps organized to demonstrate findings and implications suitable for for both the laymen (villages) and professionals to understand.	High	8.5
Modern Tool Usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modelling to complex engineering activities with an understanding of the limitations.	Creative use of GPS, drones and satellite maps for mapping and application of CAD software for layered drawings and 3-D visualization.	Moderate	Output from use of tools such as aerial photos, maps and drawings showing land boundaries, water channels and pipelines, existing infrastructure elements.	High	7.1
The engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal, and cultural issues and the consequent responsibilities relevant to the professional engineering practice.	Consideration of societal, cultural and legislative constraints in all proposals, sometimes through direct discussions with stakeholders such as residents, village representatives and leaders as well as projected impacts on individuals and the community from informed study and interactions with professors.	High	Daily discussions with stakeholders and debates among students in the process of generation of possible schemes for sustainable developments	Moderate	7.6
Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for the sustainable development.	Prior studies and research on principles and best practices in sustainable developments which are relevant for the study village. Appraisal walks around the village area and tours of surrounds to understand the potential impact of developments on the village and surrounding habitats.	Very High	Pre-trip research presentations to appreciate the need and nature of sustainable developments including cases of good practices as well as examples of failures and adverse impacts.	High	8.6
Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.	Consideration of engineering professionalism in generating solutions in the master plan with potential conflicts with unethical suggestions and demands from some stakeholders. Commitment to sound engineering investigations and design in the midst of challenging timeline and potential reworking of surveys.	Moderate	Detection and correction of wrong attitudes and values surfaced during discussions when expedient courses of actions are suggested.	Moderate	7.2
Individual and Team Work: Function effectively as an individual, and as a member or leader in diverse teams and in	Division of work in research, field surveys and report writing in accordance to individual competencies to optimize time and resources. Coordination of work elements to account for	Very High	First-hand observations of individual voluntary and proactive actions as well as group coordination, complementation	Very High	9.0

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Student Learning Outcomes [23]	**Learning Opportunities**	**FR** (Faculty Rating)	**Assessment Modes**	**FR** (Faculty Rating)	**SR** Student Rating (Average)
multidisciplinary settings.	both individual contributions as well as group decisions through group activities and interactions in both formal and informal settings. Opportunities to complement others during instances of delayed timeline or need for competent input. Opportunities for specific individuals to demonstrate leadership in specific areas of management and technical specialization.		and mutual support through numerous occasions of setbacks and unplanned disruptions.		
Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.	Setting up of an effective communication network within the team through chats and other media to facilitate decision making and actions both prior to the trip and on the fly during the trip. Formal presentations to and informal communications with different stakeholders having different levels of technical literacy. Final report writing of a technical report of professional standard and a travel journal for informal sharing. Poster presentation of learning to student community.	Very High	Observations of usage of communication network, particularly as team bonding strengthens with time. Quality of the formal presentations and informal discussions with stakeholders as well as quality of technical report, travel journal and poster.	Very High	9.1
Project Management and Finance: Demonstrate knowledge and understanding of the engineering and management principles and economic decision-making, and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.	Planning and preparation of trip and management of all program elements in the trip including unexpected incidents and disruptions to program. Execution of mission to facilitate the production of a master plan within timeline and other constraints of limited resources.	Moderate	Observations of discipline and competency in decision making in the process of trip execution	Moderate	7.3
Life-long Learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.	Personal and group reflections on knowledge and skill gaps to raise awareness of need for lifelong learning. Informal pep chats during reflection sessions to inculcate desire for continual and directed learning in context of society's changing needs and individual's aspiration and personality.	Moderate	Observations of attitudes and value towards sustained learning and pursuit of in-depth knowledge and creation of new knowledge.	Moderate	7.0

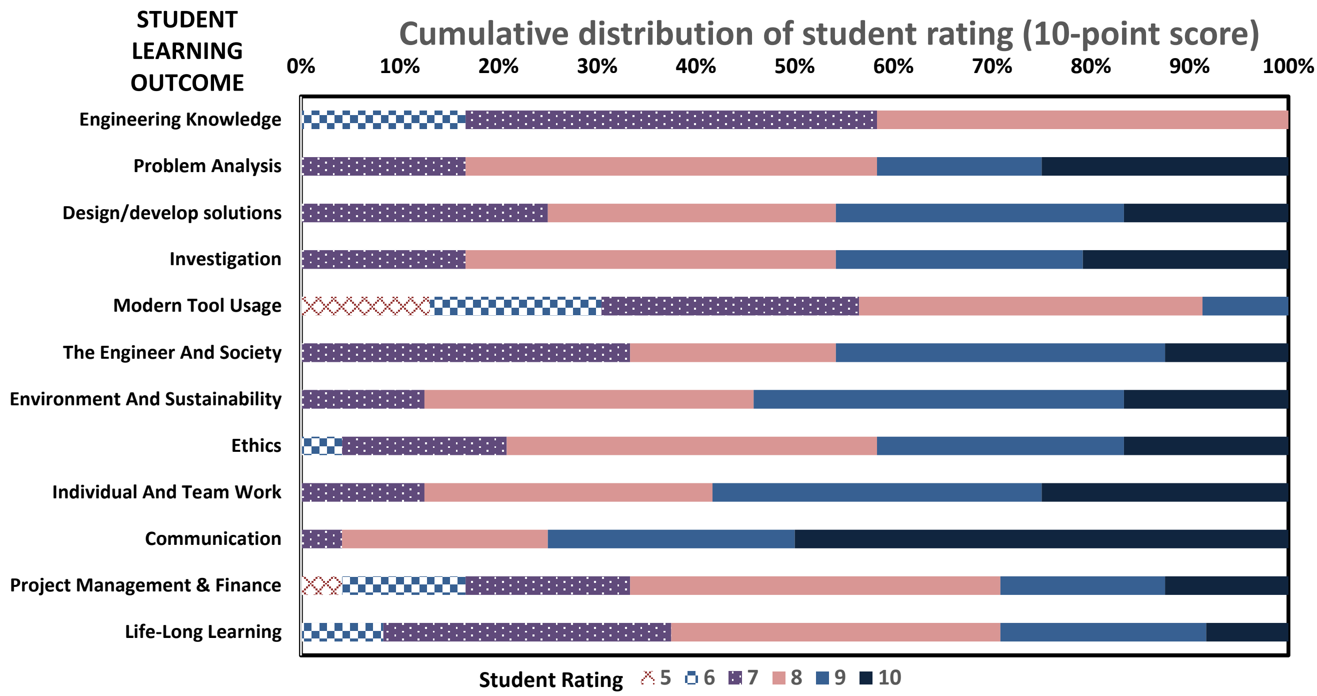

Fig. 1 Distribution of student rating of student learning outcome

Table I and Fig. 1 demonstrate that the module is effective in achieving all the SLO. Both the facilitators and students recognized very high achievement levels in several SLO, notably (1) design/development of solutions to complex real-life multi-faceted problems, (2) investigations and surveys with data validation and meaningful interpretations, (3) enhanced understanding of environmental and sustainability issues, (4) teamwork with different and diverse inputs from others, and (5) effective and varied modes of communications.

From qualitative student comments, a good number students have indicated that they are more ready to consider non-engineering issues or to include details of other engineering disciplines in planning. All students highlighted their appreciation to work in a team and have developed an increased willingness to accommodate the different views and even weaknesses of others, and learned practical aspects of conflict resolution. Many students learned how to communicate more appropriately and effectively in discussions and presentations to different stakeholders. In particular, students find it helpful to learn by observing the facilitators and how they engage village representatives and office bearers, especially in negotiations.

IV. Conclusion

It is gratifying to see how students have gained useful knowledge on sustainable development and learned critical skills beyond problem solving, such as self-reflection, team coordination as well as effective communication. The module offers a fairly complex multi-faceted problem which is still manageable and hence suitable for training. The field trip has enhanced experiential out-of-classroom learning, allowing students to have a longer retention of knowledge, skills and experience. The rural and unfamiliar environment along with the challenges encountered has pushed students beyond the comfort zone and built some measure of resilience in them. The learning is highly interactive, with the facilitators demonstrating by example rather than by presenting discourses. The continual feedback throughout the trip and emphasis on adopting the right attitudes and values, coupled with opportunities for students to do self-reflection and assessment, also meant that students appreciate the need for character and professional development beyond mere academic performance.

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