Inculcating Sustainable Development among Engineering Students, Part 1: Designing Problems and Learning Environments with Impact

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Abstract

Educating engineering students on sustainable development (SD) is a major concern in the 21st Century. Without the inculcation of SD, the students, as future innovators and problem solvers, may well be part of the problem, instead of providing the solution. Problem based learning is a possible approach to inculcate SD to have a deep impact on students. Problems were shown to be effective in engaging learning. A systematic and supportive learning environment provided through the Cooperative Problem-Based Learning framework was shown to yield deep understanding in various domains of learning. This paper describes the design of realistic problems and learning environment for inculcating SD among first year engineering students. While the problems are different each semester, there are underpinning elements maintained to reach the outcomes. Design based on constructive alignment and "How People Learn" framework, the problem is set as a competition to find engineering solutions for issues related to SD that is practical and cost effective for the society. Related industries and agencies are solicited and included in the problem to make it realistic. Divided into three stages, the problem is designed to gradually challenge students with increasing difficulty, while systematically providing the necessary support to scaffold students' learning as they develop the skills to successfully go through the process and solve the problem. Stage 1 is for learning about SD, finding information on current world scenario on the given problem, and benchmarking. Stage 2 is focused on the specific element of SD, data collection and analysis of the students' and their families' consumption or generation, and pattern of behaviour. In Stage 3, students provide a practical engineering solution that they can justify with the proper technology and cost analysis. The learning experience is shown to significantly impact the cognitive and affective domains of learning in students.

1 Introduction

Sustainable development (SD) is one of the grand challenges of the 21st Century in Engineering Education (Duderstadt, 2008). The issue is not just a matter of awareness and knowledge, it is about educating students so that SD becomes a habit of the mind that forms the character of the student. This is crucial when educating future engineers, because as innovators and problem solvers, they are the source of wealth of a nation. As stated in the UK Royal Academy of Engineering report (2007):

"No factor is more critical in underpinning the continuing health and vitality of any national economy than a strong supply of graduate engineers equipped with the understanding, attitudes and abilities necessary to apply their skills in business and other environments."

Nevertheless, in the quest for development and wealth generation, engineers need to keep in mind the need for sustainability, even though the benefit may not necessarily be explicit monetarily.

Inculcation of SD is a challenge, because the depth of the outcome should reach both a deep level of cognitive and affective domain so that the deep understanding of knowledge on SD development also influence behaviour. This includes the decisions made at the work place.

The question now is: how can we educate the future engineers so that they have a deep understanding of SD that can be applied as well as drive actions? Problem-Based Learning (PBL) is a possible approach for students to reach the desired outcomes, since research shows that PBL has been proven to engage students in deep learning, as well as change attitudes and inculcate various professional skills (Helmi, et al., 2011; Mohd-Yusof, et al., 2011; Strobel & van Barneveld, 2009; Woods, et al., 2000). This is also aligned to the philosophy of New Academia embraced in UTM that encourages learning that appreciates knowledge in accordance with our responsibility as human beings (Ujang, 2013). PBL starts with a problem that is carefully crafted to invoke interest among students to seek new knowledge to solve the problem. To support learning, Cooperative Problem-Based Learning (CPBL), was used to enable effective implementation in a typical engineering class.

This is the first of a two-part paper describes the design of problems used to inculcate SD among first year chemical engineering students in Universiti Teknologi Malaysia (UTM) in the Introduction to Engineering course. Implemented since 2004, the underpinning elements in designing and crafting the problems to gradually challenge and support students to attain deep learning is elaborated. The second part will present the results of research on the effectiveness of SD inculcation using this approach.

2 Cooperative Problem-Based Learning (CPBL)

PBL is a philosophy that needs to be adapted to the environment of the institution and the nature of the field in which it is applied. Most PBL models, however, can be expensive because they require intensive manpower, infrastructure and institutional support. The medical school model is normally implemented in small group tutorials with one dedicated facilitator that functions as the cognitive coach, while the project organized model that originated from Aalborg University is implemented in an institutional setting with small groups supervised by a dedicated instructor (Barrows, 1996; de Graaff and Kolmos, 2003). Most importantly, however, all different variations of PBL models starts the process with a realistic, if not real, problem.

For a typical engineering class setting with 30 to 60 students, Cooperative Problem-Based Learning (CPBL), which integrates CL principles into the PBL cycle, were shown to be effective in supporting students to attain deep learning in the various learning domains. CPBL was proven to develop team based problem solving skills, as well as enhance motivation and learning strategies among undergraduate engineering students (Mohd-Yusof, et al, 2011b; Helmi, et al, 2011). In a typical classroom, CPBL can be implemented by dividing students into small groups in a medium to large class. The five CL principles helps to drive students into functional learning teams: positive interdependence, individual accountability, face to face interaction, appropriate use of interpersonal skills and regular group function assessment.

The CPBL process consists of the same three phases of the PBL process, as shown in Figure 1. However, each phase is expanded to incorporate CL principles to ensure a functioning cooperative team, which is essential in providing the required support in learning and solving the problem. Students are facilitated by floating facilitators, who circulates around from group to group, or conduct the overall class sessions. In a proper CPBL environment, part of the monitoring, support and feedback can be attained from peers, especially team members, instead of solely relying on the facilitator. Phase 1 consists of the problem identification and analysis. Phase 2 consists of learning, application and solution formulation. Phase 3 is generalization, internalization and closure. In each phase, the individual activities are designed to enhance learning and accountability, which will be strengthened with team-based activities, and further supported in the overall class activities to form a learning community. The framework in Figure 1 can be used to visualize the CPBL process to support students in grasping the the whole process, as well as for facilitators to explain the significance of each step in terms of the outcomes and activities in each block as they go through each of the three phases in the CPBL cycle. A detailed description of CPBL can be seen in Mohd-Yusof (2011a).

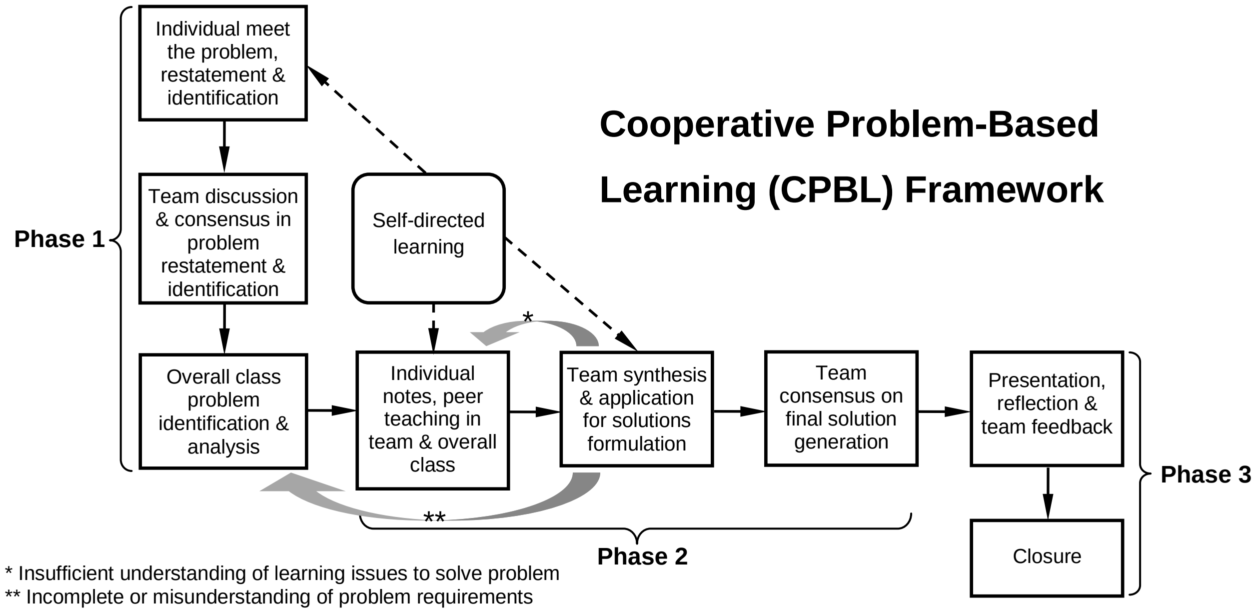


Figure 1. Cooperative Problem Based Learning (CPBL) Framework

3 Design of Learning Environment

To attain the outcomes of inculcating SD in cognitive and affective domains, the overall design of the learning environment is based on Constructive Alignment (CA) and How People Learn (HPL) framework. CA requires the outcomes to be properly aligned with assessment tasks and teaching and learning activities based on the constructivist approach, where students go through a learning environment that gives them the opportunity to construct knowledge or skills specified in the desired outcomes (Biggs and Tang, 2007). The HPL framework can be utilized for analyzing and designing learning environments through four overlapping lenses: knowledge centered, learner centered, assessment centered and community centered (Bransford, 2004). Since the CPBL framework is also underpinned on both principles, utilising CA and HPL to design the whole learning environment becomes natural.

The problem must be designed such that students will be able to understand SD activities and policies in Malaysia and throughout the world, and for the concept to have an impact on how they behave. Students also recommend an engineering solution that help to alleviate the problem. In accordance with the learner centred lens of the HPL framework, the problem is given as a competition to find engineering solutions for issues related to SD that is practical and cost effective for the society, which students can identify with. Related industries and agencies are solicited and included in the problem to make it realistic. A first year seminar course is used to support the inclusion of stakeholders by inviting them to give presentations and bringing students for related site visits.

There are normally 30 to 40 students in a class, with three sections, facilitated by different lecturers, of the Introduction to Engineering course, giving a total of around 100 students. In each class, students are divided into groups of three to five students. CL principles were explained to the students to develop functional learning teams. At the end of a CPBL cycle after each stage, students reflect on their team functioning to see what are the good actions that should be kept up, and what needs to be improved. They are encouraged to cooperate in learning, not only in their own class, but also among all students, to form a learning community, as recommended by the HPL framework

To support students in reaching the required depth in learning, the problem is divided into three stages, with each stage designed to gradually challenge students with increasing difficulty, as detailed out in Table 1. During each stage, the CPBL framework was used to systematically provide the necessary support to scaffold students' learning as they develop the skills to successfully go through the process and solve the problem. Table 1 shows the alignment of outcomes to the teaching and learning activities (TLA) and the assessment task (AT).

Table 1: Constructively aligned learning environment

Stage	Outcomes	TLA	AT
1 3 weeks	Explain sustainable development, discuss current world scenario and analyze information from several countries to benchmark current efforts in Malaysia compared to other nations around the world	Go through the whole CPBL cycle to find information and learn about sustainable development, and the local and global scenario, and present critical analysis of findings	Facilitation during in-class individual group and overall class sessions in CPBL, peer teaching notes, written report on Stage 1 and oral presentation, team and individual reflection
2 4 weeks, includes 1 week semester break	Data collection of students' and their families' consumption or generation of assigned resource to estimate and determine behaviour pattern, refine data and analysis to benchmark with local and global information to propose possible solutions.	Go through CPBL cycle to plan and collect required data at residential college and homes, perform data analysis to determine pattern of behaviour for benchmarking. Use data to justify problems to be focused on, propose possible solutions.	Facilitation during in-class individual group and overall class sessions in CPBL, peer teaching notes, written report on Stage 2 and oral presentation, team and individual reflection
3 4 weeks	Propose engineering solutions to a specific problem, get feedback on problem and possible solutions from stakeholders and focus on the best solution	Go through CPBL cycle come up with solution, fieldwork to get feedback from stakeholders of the problem, and refine solution based on practicality and cost	In-class individual group & overall class sessions facilitation, final report and poster presentation, reflection on stage 3 & overall meta-reflection

Even though the problem for each year is different, it follows the same principles and pattern, with the same outcomes as in Table 1. Stage 1 is for learning about SD, finding information on the current world scenario related to the given problem, and benchmarking. The aim of this stage is for gathering information and initiating students into the current concept of SD. From this stage, students develop the skills for information mining and self-directed learning. Stage 2 is focused on the specific element of SD and the measurement, data collection and analysis of the students' and their families' consumption or generation, and pattern of behaviour, as well as proposing various possible solutions. The aim of this stage is to get students to scrutinize their own actions and behaviour in their life as university students, and their families' habits when they collect the required data associated with the problem. In Stage 2, students develop their ability to design and plan the data gathering activities, estimation and accuracy in data gathering, and analysing as well as presenting data to form a conclusion. In Stage 3, students provide a practical engineering solution that they can justify with the proper technology and cost analysis. The aim of this stage is to use all the knowledge and information gathered from stages 1 and 2 to focus on a specific problem which they can provide an engineering solution for. Students develop their critical and creative thinking skills for solving simple engineering design problems, as well as the skill for cost analysis.

The duration of the whole problem is 11 weeks out of 14 weeks for a semester. The three contact hours per week was divided into two sessions. Students complete each stage of the problem by going through the CPBL cycle shown in Figure 1. During Stage 1, class times were spent on each CPBL phase closely facilitated by the lecturer, which functioned as scaffolding to help students learn and accomplish the required tasks, since they are new to CPBL. In Stage 2, students were facilitated through crucial CPBL phases, with more tasks being completed out of the class. When students reach Stage 3, they were able to go through the CPBL phases on their own; during this stage, lecturers had to probe for the solutions proposed, especially in terms of the technology, practicality and cost involved.

4 Crafting a Problem: An Example

Problems, which are unstructured and open-ended, provide a stimulus for learning in PBL. Problems can be crafted to serve as the backbone of learning the required content at the desired depth. They provide a context for the content that students have to learn to solve the problem. Contextualization means that the smaller learning issues and tasks are anchored to a larger task or problem, that illustrates the relevance of the objective and provides meaning of the tasks to the learners. Thus, problems motivate students to learn because they realize that they are preparing themselves for the real world as they solve the problem. A detailed description for crafting problems in engineering can be seen in Mohammad-Zamry, et al. (2012).

To make the problem manageable within the time frame of one semester, a specific aspect of sustainable development must be focused on. In accordance with the HPL framework and UTM New Academia, possible stakeholders that can be included in the problem are identified. In the 2012/13 session, the problem focused on low carbon society (LCS) in the Iskandar Region of Johor, Malaysia, where UTM is situated. The Iskandar Region Development Authority (IRDA) agreed to participate and provide prizes for the top three winning teams.

Once the theme had been identified, the "packaging" for the problem must be decided before the problem can be written. For the LCS problem, the overall problem and the details for Stage 1 was packaged in the form of a competition brochure for the first year students, as shown in Figure 2. The decision on the packaging and its design takes into account the trend of the target group, in-line with the learner centred aspect of the HPL framework. A competition brochure was chosen to attract the first year students so that they would be immersed in the problem on low carbon society. In the brochure, a brief write up to introduce the problem were given as follows:

In line with the vision of "a sustainable metropolis of international standing", Iskandar Malaysia (IM) hopes to become a low carbon-emission society by 2025. As such, Low Carbon Society (LCS) Competition is organised by the Iskandar Regional Development Authority (IRDA), in collaboration with Universiti Teknologi Malaysia. IRDA would like to solicit ideas from all levels of the community to propose innovative sustainable solutions for creating LCS. The proposed innovations will help to reduce carbon-dioxide emissions at the national level and create a road map towards a low carbon society at either a regional or city level. Innovations in IM is expected to be a showcase of the best practice not only for this region and Malaysia, but also for Asia. To ensure the practicality of the recommended solutions, benchmarking with world-wide and Malaysia practices should be conducted.

UTM
Faculty of Chemical Engineering
UNIVERSITI TEKNOLOGI MALAYSIA

LCS 2012 COMPETITION

LOW CARBON SOCIETY
UNIVERSITI TEKNOLOGI MALAYSIA

INTRODUCTION

In line with the region's vision of "a sustainable metropolis of international standing", Iskandar Malaysia (IM) hopes to become a low carbon-emission society by 2025. As such, Low Carbon Society Competition (LCS2012) is organised.
Iskandar Regional Development Authority (IRDA) in collaboration with Universiti Teknologi Malaysia (UTM) would like to solicit ideas from all levels of its community to proposed an innovative sustainable solutions for resource conservation in creating low carbon society (LCS). The propose innovations will help to reduce the amount of carbon-dioxide emissions at a national level and create a road map towards a low carbon society at either a regional or city level. The propose innovations in Iskandar Malaysia (IM) is expected to be a showcase of the best practice not only for this region and this country but also for Asian regions. In order to ensure the practicability of the recommended solutions, benchmarking with world-wide and Malaysia practices should be conducted.

OBJECTIVES

The objectives of this competition are:

- To familiarize with the concept of Low Carbon Society and eco-community.
- To differentiate different types of resource conservation efforts to reduce carbon (world wide and Malaysia scenario).
- To establish current carbon intensity in IM.
- To propose cost competitive resource conservation strategy to reduce carbon intensity in IM.
- To promote awareness in developing LCS to residential community in IM.

PARTICIPANTS

Open to all first year undergraduate students from institutions of higher learning in Malaysia.

DEADLINES

There are three stages of the contest. All contestants must go through all the three stages. All teams will go into the final round where they will compete with other contestants for the grand prize in a solid waste management Campaign Day.

- **STAGE I: FAMILIRIZATION OF LOW CARBON SOCIETY, RESOURCE CONSERVATION AND BENCHMARKING**
  Begins 2/10/2011; Due 15/10/2011
- **STAGE II: DETAIL ANALYSIS ON PARTICULAR RESOURCE CONSERVATION EFFORT**
  Begins 23/10/2011; Due 21/11/2011
- **STAGE III: PROPOSE ENGINEERING SOLUTION AND ECONOMIC ANALYSIS**
  Begins 23/11/2011; Due 20/12/2011

* Details of each stage will be given in detail later by the organizer.

PROPOSAL SPECIFICATIONS

At the end of Stage III, every participating team is required to submit a comprehensive, final written proposal that should contain, but not limited to, the following items:

1. Perform a preliminary study on LCS and resource conservation concepts Global scenario of resource conservation efforts to reduce carbon and current residential practices worldwide and in Malaysia.
2. Propose engineering solution.
3. Perform economic analysis to find the least resource conservation strategy to reduce carbon.

To support your understanding about IM scenario, IRDA will provide you with the relevant blue print and references upon request. Winning proposals are sought for projects that are viewed to be most **environmentally-sound** as well as **economical viable** based on resource conservation concept.

STAGE 1 SPECIFICATIONS

Participating teams are required to perform a preliminary study on LCS and resource conservation concepts to benchmark where practices in Malaysia compared to those at the international level, with particular emphasis on the current community practices, such as residential areas and schools. Information must be gathered from reliable sources and analyzed to determine current consumption habits and conservation efforts that can be used for benchmarking. You are required to submit a first stage report on Oct 15, 2012 before 5pm and present your findings to the evaluation panel in a seminar that will be held on Oct 16. Each team will be given 7 minutes to present followed by 3 minutes Q&A session.

RULES AND REGULATIONS

- The number of students in a group must not be more than five.
- This project should propose engineering solution for resource conservation efforts to reduce carbon intensity in IM.
- Participants are required to choose the one particular resource conservation area (e.g. water, energy, solid waste).
- Participants are given **two months** to come out with the completed proposal. Throughout the two months period, participants are given the privilege to acquire expert consultation from an experienced researcher working in the field via online forum. In addition, participants are also encouraged to seek other expert consultations such as from academicians, environmental consultants, etc. The organizer will also appoint advisors whom will guide the participating teams throughout the competition.
- Each team should submit their staggered progress report (which will contain part of the information required) at the end of every phase (which will be explained in detailed later) to the advisors to be edited.
- Besides written final proposal, every team is also expected to do an oral presentation in front of the panel of judges for ten minutes.
- Entries not complying the rules and regulations of the competition will be disqualified.
- Decisions by the judges are final.

Figure 2. Part of brochure for LCS problem

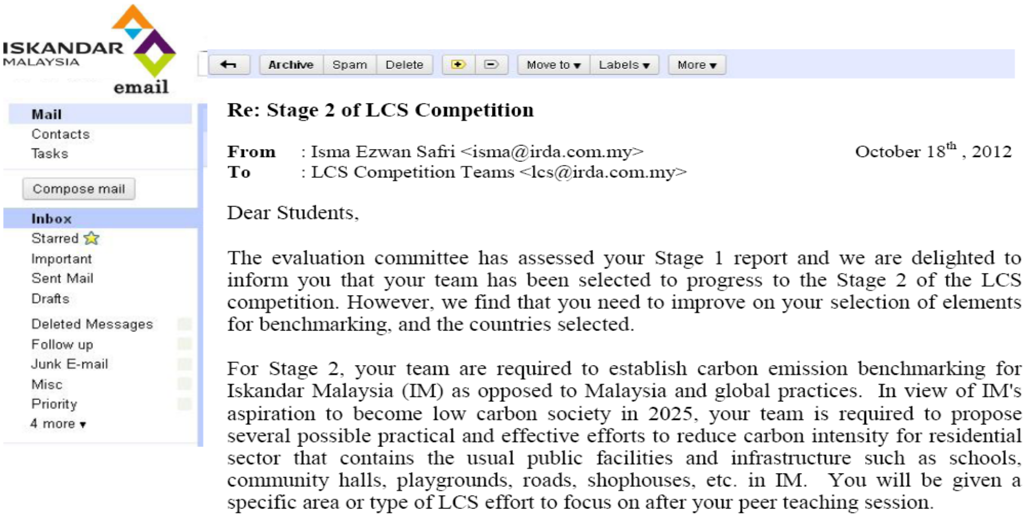
In addition, the overall objectives, the titles and deadlines of each stage were given to provide an overall view of the competition. The rules and regulations of the competition is also included. In the brochure, specific instructions for Stage 1 is given as follows:

Participating teams are required to perform a preliminary study on LCS and resource conservation concepts to benchmark where practices in Malaysia compared to those at the international level, with particular emphasis on the current community practices, such as residential areas and schools. Information must be gathered from reliable sources and analyzed to determine current consumption habits and conservation efforts that can be used for benchmarking.

In crafting the problem, resources, that students will need, whether collected or given, should be determined. In addition, the location and timing of where, what, how and who to get the information or data from should also be planned. For Stage 1 of the LCS problem, students performed their own literature search to find and learn the required information and concepts to determine the current status in Malaysia and world-wide, as given in the brochure. During this stage, a presentation on the overview of SD was given by an expert in the area during of the first year seminar.

In Stage 2, students had to refine their carbon emission benchmarking for the Iskandar region, and determine the consumption or generation behaviour of a university student, and a family in Malaysia. They also proposed several possible solutions to reduce carbon emission. Figure 3 shows the details for Stage 2 given in an email. Mr. Isma, a Vice President in IRDA whose name was used in the problem, gave a talk on the vision for LCS in the Iskandar region in the first year seminar. Each team was randomly assigned a specific topic, either energy, water or solid waste, and a specific type of area to focus on. Students have to learn about designing data collection and estimation, before collecting the required data at their residences and at home during their semester break. Auditing their own use is very important to make them realize that everyone is accountable for increasing carbon emission.

In Stage 3, the problem was more challenging as the teams focused on a specific issue in the assigned area and category to propose a solution for the problem. Figure 4 shows part of the email to detail out Stage 3. IRDA assisted in visits to sustainable model houses and a school. In addition, the teams arranged visits to relevant sites to get the feedback from the community on the possible solution.



Re: Stage 2 of LCS Competition

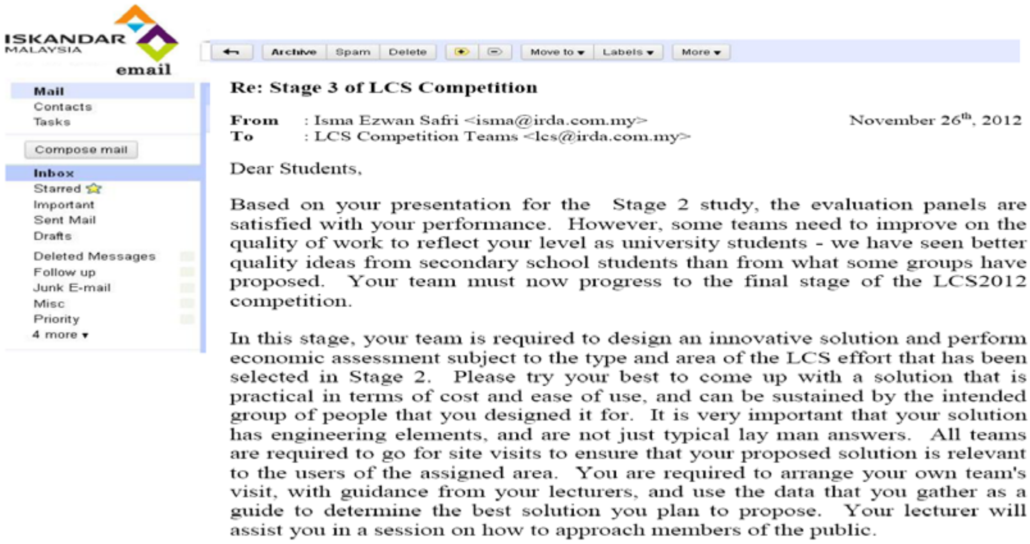
From : Isma Ezwan Safri <isma@irda.com.my> October 18th , 2012
To : LCS Competition Teams <lcs@irda.com.my>

Dear Students,

The evaluation committee has assessed your Stage 1 report and we are delighted to inform you that your team has been selected to progress to the Stage 2 of the LCS competition. However, we find that you need to improve on your selection of elements for benchmarking, and the countries selected.

For Stage 2, your team are required to establish carbon emission benchmarking for Iskandar Malaysia (IM) as opposed to Malaysia and global practices. In view of IM's aspiration to become low carbon society in 2025, your team is required to propose several possible practical and effective efforts to reduce carbon intensity for residential sector that contains the usual public facilities and infrastructure such as schools, community halls, playgrounds, roads, shophouses, etc. in IM. You will be given a specific area or type of LCS effort to focus on after your peer teaching session.

Figure 3. Part of the email detailing Stage 2 of the LCS problem



Re: Stage 3 of LCS Competition

From : Isma Ezwan Safri <isma@irda.com.my> November 26th, 2012
To : LCS Competition Teams <lcs@irda.com.my>

Dear Students,

Based on your presentation for the Stage 2 study, the evaluation panels are satisfied with your performance. However, some teams need to improve on the quality of work to reflect your level as university students - we have seen better quality ideas from secondary school students than from what some groups have proposed. Your team must now progress to the final stage of the LCS2012 competition.

In this stage, your team is required to design an innovative solution and perform economic assessment subject to the type and area of the LCS effort that has been selected in Stage 2. Please try your best to come up with a solution that is practical in terms of cost and ease of use, and can be sustained by the intended group of people that you designed it for. It is very important that your solution has engineering elements, and are not just typical lay man answers. All teams are required to go for site visits to ensure that your proposed solution is relevant to the users of the assigned area. You are required to arrange your own team's visit, with guidance from your lecturers, and use the data that you gather as a guide to determine the best solution you plan to propose. Your lecturer will assist you in a session on how to approach members of the public.

Figure 4. Part of the email detailing Stage 3 of the LCS problem

Deliverables that students must submit were clearly indicated in the problem. Dates for report submission and presentation at the end of each stage were stated in the brochure that contained the overall problem. In addition, the expectations on the standard were also indicated in the problem as well as through a properly designed grading rubric. Since there are three stages of the problem, students received feedback on the earlier stage before submitting the deliverables for the next stage so that they may get feedback, in accordance with the Assessment Centred aspect of the HPL framework. At the end of Stage 3, all teams submit a final overall report, and gave a poster presentation, where the panel judges consists of experts in the area, and several personnel from IRDA.

5 Conclusion

The inculcation of SD among first year engineering students can be attained through proper design of problems and learning environment. The CPBL framework provided support for learning in both the cognitive and affective domains as students encounter increasingly challenging aspects of the problem crafted. The sample problem included shows how the problem can be crafted for effective implementation in a typical engineering course. Finally, the UTM philosophy to encourage the New Academia (Ujang, 2013) in achieving quality education provides a conducive institutional environment to foster evidence-based innovation in learning that has significant positive impact for students.

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