EDUCATION FOR SUSTAINABLE DEVELOPMENT USING DESIGN THINKING AND APPROPRIATE TECHNOLOGY

Poh-Hui Chua

Sin-Moh Cheah

Singapore Polytechnic

ABSTRACT

The Brundtland Commission's definition of Sustainable Development (SD) clearly highlights the importance of the three dimensions of sustainability, namely environmental, social and economic, when one considers development. It also stresses the need for greater equity around the world, all within limits of the planet's finite resources. In 2008, an inter-ministerial committee on sustainable development (IMCSD) was set up to formulate a national strategy for Singapore's sustainable growth in response to mounting global resource scarcity. The Diploma in Chemical Engineering in Singapore Polytechnic, having recognized the importance of SD, has adopted a two-pronged approach to introduce SD into its curriculum: (1) Integration into selected core modules across all three years of study; and (2) SD-themed Year 3 *Final Year Projects* (*FYPs*). The first approach served to support the implementation of the latter and was discussed extensively in our earlier works. In the present work, the second approach takes the center stage and we will present our way of linking chemical engineering concepts with elements of SD. This was achieved via the conduct of a *FYP* with the aim of designing and developing a sustainable solution for high-density aquaculture for the diminishing local fish farming industry. The project involved the use of design thinking to assist in the Conceive and Design phases of the project. Besides, students incorporated "appropriate technology" in their designs to promote sustainability practices. Findings suggest that design thinking is able to empower our students to come out with creative ideas that work. It also dawned on us that appropriate technology does help with sustainability practices and its application is indeed suitable at the diploma-level where students have yet to master a high level of technical competencies like university undergraduates do. Finally, deriving from the learning points gained, we outline a more holistic approach which the diploma's course management team is embarking on to further drive SD infusion.

KEYWORDS

Sustainable development, chemical engineering, CDIO skills, integrated curriculum, design thinking, appropriate technology.

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses".

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) in Singapore Polytechnic (SP) had adopted CDIO as the organizing education framework for a major curriculum redesign initiative in 2007. Various CDIO skills such as teamwork and communication, personal skills and attitudes (e.g. critical and creative thinking, managing learning, holding multiple perspectives, hypothesis testing) have been integrated into the diploma's three-year curriculum. Having accomplished the above, the DCHE Course Management Team (CMT) is now embarking on introducing an equally important element, sustainable development, to its curriculum.

Sustainable Development (SD) implies attaining economic growth not at the expense of environmental quality. The Brundtland Commission [1] clearly highlights the importance of the three dimensions of sustainability, namely environmental, social and economic, when one considers development. The definition of SD in the report is very well known and often cited. The report refers SD to as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". This resonates profoundly with the DCHE CMT's ideal to equip its students with a better understanding of SD and develop a greater appreciation that they can indeed make a difference in response to mounting global resource scarcity.

Cheah et al. [2] had previously provided a detailed review of challenges faced in integrating SD into an engineering curriculum. The authors also reported on a pilot run of introducing SD into a core module, and outlined plans for broader plan for integrating SD into the DCHE's three-year curriculum. This present paper is an update of our effort in this important area.

SUSTAINABLE DEVELOPMENT AND THE DIPLOMA IN CHEMICAL ENGINEERING

We adopted a two-pronged approach:

(1) Integrate SD into selected core chemical engineering modules across all three years of the DCHE curriculum: linking chemical engineering concepts with SD.
(2) Practice SD in Year 3 *Final Year Projects* (*FYPs*): students apply appropriate chemical engineering principles for selected *FYPs* involving SD. Emphasis here is not just on students being able to integrate their technical knowledge gained over the years of study, but also to demonstrate understanding in considering social and economic aspects of SD as well.

The first approach is meant to support the execution of the second approach when the curriculum change reaches its steady-state. We have decided to try out both approaches simultaneously in Academic Year (AY) 2011/2012 so that we can learn as soon as possible students' experience in the integration effort, and make the necessary improvements. The first approach had been covered by the second author as mentioned earlier [2]. With this approach we attempt to infuse SD into a number of core modules where there are relevant connections. This also avoids the problem highlighted by a number of authors whereby the coverage of SD at some institutions had narrowly focused only on environmental issues [3], [4].

This paper focuses on the second approach, sharing the outcomes so far, and how we intend to further enhance the integration of SD and the learning experience for a wider range of students.

Final Year Projects with Emphasis on Sustainable Development

We will outline the approach through a particularly successful project concerning fish farming in Singapore. Firstly, a brief outline on food supply and fish farming is needed for context. As of 2011, the world population had reached an estimated 7 billion people. With the increased population, food resources will be put under tremendous strain. Fish are an important element of food supply, and fishing is a vital factor in global employment. Today, people are taking far more fish out of the ocean than can be replaced by those remaining. According to the estimates of Food and Agriculture Organization (FAO) of the United States, 53% of the world's fisheries are fully exploited, and 32% are overexploited, depleted, or recovering from depletion [5]. To make things worse, new projections suggest that the contribution of fish to the global food supply is likely to decrease in the next two decades as demand for fish increases and production flags [6]. Ocean fish farming activities are often subject to uncontrollable conditions including weather, currents, disease and human precision. Damages caused by any number of unplanned events such as hostile weather, natural predators and human errors could spell disaster for ocean fish farming. Without a doubt, traditional ocean fish farming is not sustainable.

In light of the above, introducing solutions built on the basis of SD is of rising importance. Having recognized the need to reinforce the socio-economic aspects of SD, SP has made social innovation projects a key platform for delivering holistic education to its students over the past two years. Social innovation is classified as the process of inventing, securing support for, and implementing novel solutions to social needs and problems [7]. It has garnered a great deal of attention in recent years due to a growing sense of urgency to solve various global problems brought upon by aging population, rising cost of health care, depletion of natural resources, widening income gap, climate change, illiteracy and poverty, etc. In DCHE, several social innovation-themed Year 3 *FYPs* in collaboration with local farmers in Singapore were pioneered to assist them in sustainable practices, thereby strengthening student engagement in the socio-economic aspects of SD. These farms are few of the surviving ones in land-scarce Singapore located in a more remote north-west region of the island nation.

This present paper discusses one such *FYP* which aimed to design and develop a sustainable solution for high-density aquaculture with enhanced controllability. This *FYP* was undertaken by two teams of three-membered student groups in succession which spanned over duration of two years where the principles of CDIO were applied. To help students with the Conceiving and Designing phases, design thinking was introduced into the *FYP* [8]. The design thinking (DT) approach focuses on three mutually supporting elements, namely that of user empathy, technical feasibility and economic viability, as shown in Figure 1 [9].

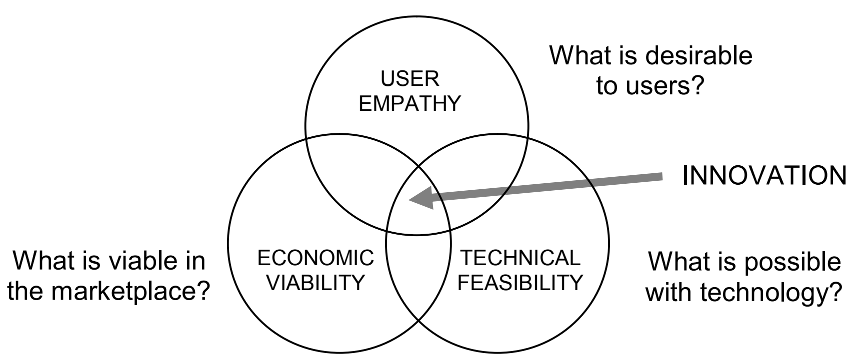

Figure 1: The DT Framework

Dos Santos Martins [10] had noted that sustainability-related problems are not easy to define, and hence are "wicked" in nature [11]. These are problems the nature of which changes over time and are characterized by complex, interacting issues that often emerge as a result of trying to define, understand and resolve the problem. Dos Santos Martins suggested that DT is needed to identify the root cause of the problem(s). Having been exposed ourselves to DT recently, we decided to introduce it into the *FYP*. However, as our Year 3 students were not familiar with DT at the time of this pilot run (AY2011/2012), a special workshop was conducted for them with the assistance of staff from Department of Educational Development (EDU). DT was subsequently introduced into the DCHE curriculum for Year 1 students effective from AY2011.

The *FYP* in discussion here, together with several others we introduced as mentioned above, focuses on using what is commonly referred to as "appropriate technologies", a term attributed to Schumacher [12]. Appropriate technologies are usually characterized as small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community [13]. The goal of appropriate technology is to raise the standard of living for the developing communities without condescension, complication and environmental damage. This goal unmistakably matches that of social innovation projects and we believe that appropriate technology can potentially serve as a tool to help solve numerous social-economic issues facing the communities in need. The farmers whom the *FYP* students worked with represent one such community. They were earning very little due to losses from high fish mortality rates and were living from 'hand to mouth' – so to speak. The students empathized with what the farmers were going through and had a strong urge to help them achieve a better financial livelihood. In the course of the *FYP*, the students had proposed and implemented a range of simple concepts and designs that clearly constitute 'appropriate technology' in the context of this paper. These included:

(1) Stackable fish tank design to achieve maximum space efficiency.
(2) Isolated fish tanks to minimize cross contamination and make monitoring easier.
(3) Simple U-shaped siphoning tubes to facilitate waste removal from tanks by means of pressure difference without the use of a pump.
(4) Inclusion of check valves to prevent pump damage as a result of backflow of water in the event of a power failure.
(5) Unique missile-head-shaped fish tanks to reduce the likelihood of fish fries getting trapped at the water-air interface due to water surface tension.
(6) Inclined base of the fish tank to allow for accumulation of wastes at one corner for ease of removal.

KEY LEARNING POINTS

A focus group discussion was conducted to solicit feedback from the students on how they felt the FYP had helped them better appreciate elements of SD via the application of DT and appropriate technology. The focus group discussion (consisted of the six FYP students and a moderator) was structured around a set of carefully predetermined questions but the discussion was allowed to flow freely, facilitated by the moderator. The participants had been informed that all responses gathered from the discussion would only be used for the purpose of this present work and they would be treated in a highly confidential manner whereupon all identities are protected. We also reflected on our own practices of introducing DT into *FYP*. The followings are major learning points synthesized from these efforts:

(1) Our students appeared to be comfortable with using DT in their *FYP*. When asked on how they felt DT was useful in doing the project, one of the students had the following to say:

> "It provides us with a different frame to work with, which is more flexible and open to ideas as compared to the usual engineering frame of thinking. This frame provides us with lots of brilliant ideas to work on, towards our final idea."

The student further elaborated that one of the farmers whom they were in collaboration with was impressed by the idea his *FYP* group had come out with using DT. Specifically, the students borrowed the concept of multi-storey flat housing which is typical of land-scarce Singapore and put it in the context of fish farming. This allowed "storeys" of fish tanks to stack over one another, thus permitting more fish to be reared per unit area. In addition, the fish were effectively partitioned to make monitoring easier and alleviate the risk of cross contamination. The farmer expressed that it was indeed an ingenious and inexpensive solution that worked for him.

(2) We find that appropriate technologies meet our *FYP* needs well. Appropriate technologies are often perceived as "low tech" and unimportant, and not usually addressed in engineering education or university research [14]. However, we felt that they are indeed very suitable at the diploma-level; as our students need not master a very high level of technical competencies at this level of study. Our *FYPs* mostly fall within the categories of gate-to-gate or cradle-to-grave scales as described by Murphy et al. [15]. Besides the high-density fish farm project, documented in this paper, our students also produced several other interesting pilot plants including waste conversion to biogas and fertiliser, pedal-power filtration, floating toilet for flood-prone areas, etc. One of the project students shared how he thought about the fish tank design that was put in place:

> "I think what we had used is technology that fits the purpose. It does not need to be sophisticated to be effective. They are just some basic science and chemical engineering principles."

When probed further on how his prior chemical engineering modules had helped him during the *FYP*, he felt that it enabled him to figure out which specific areas to zoom in on when attempting to solve particular problems. The specific emphasis on the use of appropriate technology appears to have helped to address the insecurity and lack of confidence in applying chemical engineering principles learnt at the diploma-level expressed by the students in our earlier efforts [2]. And it was through research and repeated hands-on activities which led him to gain a deeper internalization of the concepts. He felt that the *FYP* is a suitable platform to allow his team with greater autonomy to apply suitable technology in solving a problem.

(3) We believed that "marrying" DT and SD made pedagogical sense. Several authors had recently written about the importance of design and DT in SD [16], [17]. Nagel et al. [18], in particular, make the case that design and sustainability are not mutually exclusive, and that if we are to prepare our students to deal with the complex problems of sustainability, we must provide them with a holistic education incorporating all contexts of sustainability. The incorporation of DT also helped to inject some elements of creativity into the use of appropriate technology to attain SD goals. This is best summed by Schumacher [12] himself, who wrote:

> "Although we are in possession of all requisite knowledge, it still requires a systematic, creative effort to bring this technology into active existence and make it generally visible and available. "

(4) Most significantly, we learnt that in order to make learning SD meaningful for students, we need to situate it firmly in the context of engineering practices, and hence we need to design activities that can bring about the desired learning in a manner similar to the way we integrated other CDIO skills such as teamwork, communication, critical thinking, etc. Merely introducing activities that highlight application of chemical engineering principles in SD is inadequate. As argued by Byrne and Fitzpatrick [19], "Embedding sustainability…. alone cannot effectively demonstrate how sustainability should be the context through which twenty first century engineering must be practised." Our previous learning tasks for various CDIO skills are predominantly based on three to four hours of laboratory activities where the skills are infused. Learning activities on SD undoubtedly demands more time than that! Having more *FYPs* which are related to SD provides one such avenue.

(5) At this juncture, we have yet to assess how well SD had been practiced in the *FYPs*. As noted by Allen and Shonnard [20], "… the tools for converting sustainability concepts into the types of quantitative design approaches and performance metrics that can be applied in engineering design are just emerging". We are not concerned with assessment at this point in time. What is more important for us is that students have the opportunity to apply what they learn in real life contexts which results in more meaningful learning, enhanced confidence in their own abilities to contribute to SD; and more importantly, from an educational perspective, sustain interest in chemical engineering.

MOVING AHEAD: OPPORTUNITIES AND CHALLENGES

Going forward, drawing from the learning points gained, we proposed a framework as shown in Figure 2 to achieve what Sterling called "Educational as Sustainability" [21]. It shows how DT supports the Conceive and Design phases of CDIO by incorporating user needs and problem formulation; which in turn help address the social dimension of SD. The use of appropriate technology supplements the economic viability aspect of DT as well as the economical dimension of SD.

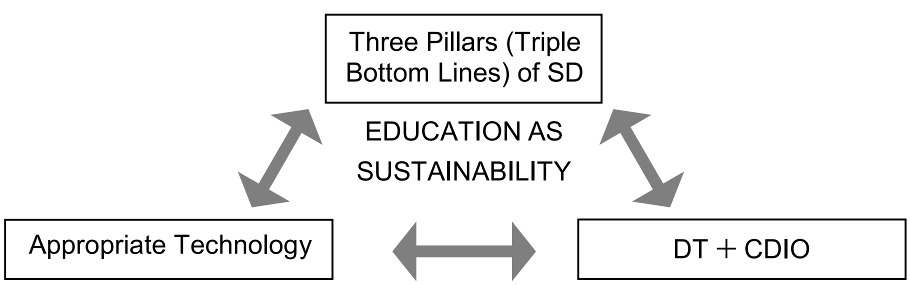

Figure 2. Components of Education as Sustainability

Trevelyan [22] asserted that engineering is a technical and a social discipline at the same time, and reported that several studies of engineering practice have demonstrated the significance of social relationships in many different ways. To achieve such balanced goals requires a curriculum that focuses on design and management of sustainable technology, research into environmental and social impacts, limitations and living within those limitations, and management of resources from cradle to cradle [23]; so that our students see meaning in what they are learning and doing. This is supported by Huntzinger et al. [24] who stress that “students need not only the knowledge base to generate effective engineering solutions; they need the intellectual development and awareness to understand the impact of their decisions”.

The framework outlined in Figure 2 complements our intention to design a more holistic approach to integrate DT into our 3-year DCHE curriculum, as shown in Figure 3 [8]. Note that we had already embedded the teaching of DT into the first year. What follows are some of our plans to continue our effort in further enhancing the students’ learning of this important subject.

CONCEIVE | DESIGN | IMPLEMENT | OPERATE

Year 1	Year 2	Year 3
Introduction to Chemical Product Design (ICPD)	*Chemical Product Design and Development (CPDD)*	*Final Year Project (FYP)*
DT: User Empathy	DT: Technical Feasibility; Economic Viability	

Figure 3. Integration of DT into Chemical Product Design [8]

We will review the Year 1 module *Introduction to Chemical Product Design* (*ICPD*) and Year 2 module *Chemical Product Design and Development* (*CPDD*), focusing on the balanced pursuit of the three SD goals of ecological health, social equity, and economic welfare.

For example, the revised *ICPD* will introduce students to the various issues related to SD, e.g. provision of clean water, alternative fuel, healthcare, etc. These are issues that had been identified by AIChE where chemical engineering can play crucial roles [25]. The emphasis is on using DT to examine in details the identified issues and come up with product ideas aimed at addressing these issues. The ideation concepts must demonstrate strong human desirability principles. When the students study *CPDD*, they will then apply the chemical engineering principles learnt in other core modules to assess the technical feasibility of their product ideas and to further develop suitable ones and to begin design suitable product prototypes. They also need to be mindful of the economic viability of their product prototypes. Lastly, they can carry on the product ideas and prototypes into Year 3 *FYP* for test-bedding and possible implementation.

We also plan to strengthen our partnership with local farmers and scale up our collaboration, so that more students can work on various projects in the farm; instead of only 6-9 students in the present arrangement. We have made changes to our course structure to shift a Free Elective module from Year 3 into our Year 2 curriculum so that at least a class of students (approximately 20-24) can opt to take up this form of project-based learning, which offers the potential of continuing their work into Year 3 as their *FYPs*. The rest of the students can still opt for other modules offered in the Free Elective basket.

Having a free elective module in Year 2 will also create opportunities for our students to take part in multi-disciplinary projects on SD with students from other diplomas, both within the school as well as other academic schools. O’Rafferty [26] has argued that inter-disciplinarity is a necessary requirement for addressing sustainability issues. This may become the most significant challenge yet; as it will not be easy for various diplomas to make changes in their respective course structures to accommodate such a learning arrangement.

There is also the challenge of coming up with a syllabus for such a module in the first place. This syllabus will be very different from others in the "traditional" chemical engineering curriculum, which pretty much follows the "traditional" Lecture:Tutorial:Practical model. At the point of writing this paper, we have yet to draft the syllabus.

Lastly, there are challenges in timetabling to free up hours for out-of-classroom learning that this approach entails. Subject to timetabling provisions, we hope to have ideally up to one day where students can spend their time in the farm, learning outside of the classroom. Such a learning environment will expose students to a diversity of disciplinary and stakeholder perspectives – as aptly summarized by van Dam-Mieras [27]: "Most learning environments in traditional formal education do not optimally support that type of learning." Likewise, Cortese [28] argued for a process of education that "emphasize active, experiential, inquiry-based learning and real-world problem solving… in the larger community", noting that helping students become "socially vibrant, economically secure, and environmentally sustainable" is what makes for a successful higher education.

We believe that this new way of learning will help students gain a better understanding of the significance of the three overlapping circles of SD and develop a greater appreciation that they can indeed make a difference. Along the way, students can also build up their ability to make better judgments based not just on technical grounds, but also on social and economic reasoning. The capacity of deeper understanding of non-technical issues can certainly enhance the ability of our students to consider all relevant socio-economic issues prior to application of technical solutions. This in fact, had been identified as one of the key "sustainability competencies" of engineers [29].

We will also work towards integrating ethics and SD; as these two topics are very closely intertwined. As noted by Kibert et al. [30], SD is grounded on the ethical commitment to the well-being not only of contemporary populations but also the well-being and enhanced opportunities of future generations. The application of sustainability framework henceforth requires a better understanding of the ethical concepts which support it.

CONCLUSION

To meet the vision of "Education as Sustainability", significant changes still need to be made to our curriculum and the way our students learn. Byrne and Fitzpatrick [19] noted that "… once a curriculum which emphasizes sustainability as the context through which all engineering practice must take place is in situ, engineering graduates will be better equipped to comprehend the very significant challenges ahead, to work with other disciplines and stakeholders in addressing these challenges and indeed take the lead in our most important endeavour yet."

While the DCHE curriculum has not quite reached the situation envisioned by these authors, we believe that our approach in executing collaborative and experiential *FYPs* directed at real community concerns in context, supported by various activities right from Year 1 and continuing through Year 2, represents the right direction towards achieving that goal. As far as education as sustainability and sustainable development is concerned, we will continue to fine tune our educational efforts in impacting students' thinking and feelings of human relevance towards this critical global need.

REFERENCES

[1] United Nations (1987). "Report of the World Commission on Environment and Development." General Assembly Resolution 42/187, 11 December 1987. Retrieved: 2007-04-12

[2] Cheah S.M., K. Yang and Sale, D. (2012). "Pedagogical Approach to Integrate Sustainable Development into Engineering Curriculum", *8th International CDIO Conference*, July 1-5; Brisbane, Australia

[3] Kagawa, F. (2007). "Dissonance in Students' Perceptions of Sustainable Development and Sustainability: Implications for Curriculum Change", *Int. J. Sustain. High. Educ.*, Vol 8; pp.317-338

[4] Segalas J., Ferrer-Balas D. and Muller K.F. (2010). "What Do Engineering Students Learn in Sustainability Courses? The Effect of the Pedagogical Approach", *Journal of Cleaner Production*, Vol. 18; pp.275-284

[5] Food and Agriculture Organization (FAO) (2010) *State of World Fisheries and Aquaculture (SOFIA) - SOFIA 2010*. FAO Fisheries Department.

[6] Williams, M. (1996). "The Transition in the Contribution of Living Aquatic Resources to Food Security", Food, Agriculture, and the Environment Discussion Paper 13, International Food Policy Research Institute, Washington, D.C., pp. 3, 24.

[7] Hartung, R. (2012). "Thinking out of the Box for Social Good", *Challenge,* Jan/Feb Issue; Public Service Division, Government of Singapore, Prime Minister's Office

[8] Ng, H.T. and Cheah, S.M. (2012). "Chemical Product Engineering using CDIO Enhanced with Design Thinking", *8th International CDIO Conference*, July 1-5; Brisbane, Australia

[9] Brown, T., (2009). "Change by Design: How Design Thinking Transforms Organizations and Inspires Innovation", HarperBusiness, 2009.

[10] Dos Santos Martin, R.H. (2010), "Sustainable Development Requires an Integrating Discipline to Address its Unique Problems – Design Thinking", *Journal for a Global Sustainable Information Society*, Vol.8, No.1

[11] Rittel, H.W.J. and Webber, M.M. (1973). "Dilemmas in a General Theory of Planning", *Policy Sciences*, Vol.4; pp.155-169

[12] Schumacher E.F. (1973). "Small is Beautiful: Economics as if People Mattered", Blond & Briggs Ltd, London

[13] Hazeltine, B. and Bull, C. (1999). Appropriate Technology: Tools, Choices and Implications, San Diego: Academic Press.

[14] Sandekian, R., Amadei, B., Bielefeldt, A., and Summers, R.S. (2007). "Engineering for Poverty Reduction: Challenges and Opportunities", *5th Latin American and Caribbean Conference for Engineering and Technology*, May 29-June 1, Tampico, Mexico

[15] Murphy, C.F., Allen, D., Allenby, B., Crittenden, J., Davidson, C.I., Hendrickson, C. and Matthews, H.S. (2009). "Sustainability in Engineering Education and Research at U.S. Universities", *Environ. Sci. Technol.*, Vol.43; pp.5558-5564

[16] Wahl, D.C. and Baxter, S. (2008). "The Designer's Role in Facilitating Sustainable Solutions", *Design Issues*, Vol.24, No.2, pp.72-83

[17] Young, G. (2010). "Design Thinking and Sustainability", Available at http://zum.io/wp-content/uploads/2010/06/Design-thinking-and-sustainability.pdf; accessed June 12, 2012

[18] Nagel, R.L., Papas, E.C. and Pierrakos, O. (2012). "On a Vision to Educating Students in Sustainability and Design – The James Madison University School of Engineering Approach", *Sustainability*, 4, pp.72-91

[19] Byrne E.R. and Fitzpatrick J.J. (2009). "Sustainability on Engineering Programmes: The Need for a Holistic Approach", North East American Society of Engineering Education Conference: Engineering in the New Global Economy. April 3-4; Newport, Connecticut, USA

[20] Allen D.T. and Shonnard D.R. (2012). "Sustainable Engineering: Concepts, Design, and Case Studies", Prentice Hall, Pearson

[21] Sterling, S. (2001). Sustainable Education – Re-Visioning, Learning and Change, Schumacher Briefings No.6, Green Books, Dartington, UK

[22] Trevelyan, J. (2009). "Steps Towards a Better Model of Engineering Practice", Proceedings of the Research in Engineering Education Symposium, July 20-23; Queensland, Australia

[23] Donnelly, R. and Boyle, C. (2006). "The Catch-22 of Engineering Sustainable Development", *Journal of Environmental Engineering*, February Issue; pp.149-155

[24] Huntzinger D.H., Hutchins M.J., Gierke J.S. and Sutherland J.W., "Enabling Sustainable Thinking in Undergraduate Engineering Curriculum", *Int. J. Engrg Ed*. Vol. 23, No 2, 2007, pp.218-230.

[25] AIChE (2007). "Strategic Report on Societal Impact", American Institute of Chemical Engineers

[26] O'Rafferty, S. (2011). "Interdisciplinarity, Design Thinking and Sustainable Development: Strategies for UK Higher Education", The Higher Education Academy, UK

[27] van Dam-Mieras, R. (2005). "Learning for Sustainable Development: Is it Possible within the Established Higher Education Structures?" in Drivers and Barriers for Implementing Sustainable Development in Higher Education, Edited by Holmberg J. and Samuelsson B.E., Göteborg Workshop, December 7-9; Goteborg, Sweden

[28] Cortese, A.D. (2003). "The Critical Role of Higher Education in Creating a Sustainable Future", *Planning for Higher Education*, Vol.31, No.3, March-May Issue; pp.15-22

[29] Parkin, S. and Foxley, D. (2004). "Sustainability Competencies for Engineers", Forum for the Future.

[30] Kibert, C.J., Thiele, L., Peterson, A. and Monroe, M. (2011). "The Ethics of Sustainability", John Wiley & Sons Ltd, UK

ACKNOWLEDGEMENTS

The authors would like to thank Mr. Dennis Sale, senior education advisor from the Department of Educational Development (EDU), for his enthusiasm and valuable advice on the paper.

BIOGRAPHICAL INFORMATION

Poh-Hui Chua is a lecturer in the Diploma in Chemical Engineering (DCHE), Singapore Polytechnic. He is currently lecturing on topics including introduction to chemical engineering, and quality management and statistics. He is also given the teacher advisor for the DCHE Student Chapter, a facilitator in the Polytechnic's Social Innovation Projects, and a member of the DCHE Course Management Team.

Sin-Moh Cheah is a chemical engineer turned academic. He is the Deputy Director in Singapore Polytechnic, overseeing various applied sciences diploma, including the Diploma in Chemical Engineering. He has lectured on various topics including chemical engineering principles, separation processes, and chemical reaction engineering. His current portfolios include curriculum revamp, academic coaching and mentoring, and using ICT in education. His current scholarly interests are learning pedagogy, curriculum re-design and program evaluation.

Corresponding Author

Mr. Poh-Hui Chua
School of Chemical & Life Sciences,
Singapore Polytechnic
500 Dover Road, Singapore 139561
+65 6870 4648
ph_chua@sp.edu.sg