CDIO AS CURRICULUM MODEL FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT

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ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering of Singapore Polytechnic (SP) in transforming its chemical engineering education to develop a curriculum model for Education for Sustainable Development (ESD) that meets the dual-purpose of (1) satisfying industry requirements with the necessary technical knowledge and soft skills (CDIO skills), so that the students are competent in the workplace; and (2) encouraging them to serve the broader needs of society, especially those at the bottom-of-the-pyramid. This represents our response to the SP-wide initiative of delivering holistic education to our students so that they are "competent, versatile, creative and innovative, imbued with sound values and excel in work and life so as to achieve our Vision of being "Work-ready, Life-ready and World-ready."

We firstly outline key literature on ESD and explore the challenges faced by higher education in meeting the needs of ESD. Secondly, we explain how we have used previous learning and development activity in CDIO implementation to design our model of ESD. The unique features of our model are highlighted to illustrate how this can lead to the development of innovative chemical products. The model also integrates the use of design thinking and appropriate technology – the former to complement the "Conceive" and "Design" stages, and the latter to support the "Implement" and "Operate" stages of chemical product engineering. We explain how we also "mapped" the three elements of design thinking to the three pillars of sustainable development. We argue that this overall framework provides the basis to address both the cognitive and affective domains of learning, which better fulfils the desired graduate attributes of being work-, life- and world-ready.

The paper also shares some of the challenges we faced, namely in scaling-up the learning experience for all students, logistical difficulties, and lack of multi-disciplinarity in student involvement. Finally, we discuss possible future developments to further strengthen our effort in this important curriculum area.

(300 words)

KEYWORDS

Sustainable development, chemical engineering, design thinking, Standards 3, 7

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) course of Singapore Polytechnic (SP) adopted the CDIO framework (www.cdio.org) as the basis for its 3-year curriculum since 2007 to produce the next generation of engineers. The framework provides students with an education stressing engineering fundamentals set in the context of Conceiving, Designing, Implementing, Operating real-world systems and products.

We have recently completed a review of our CDIO implementation effort over the past several years (Cheah et al., 2013). In this paper, we share our latest effort to transform our course from a traditional content-based curriculum to one of an emerging paradigm which Sterling (2001) termed “sustainable education”. This transformation builds on our past efforts to integrate various CDIO skills (e.g. teamwork, communication, thinking, ethics, sustainable development) and design-implement experiences for our capstone projects.

A unique feature of our effort is that we have integrated chemical process design and chemical product design. This is to balance the curriculum towards utilizing the knowledge in the “traditional mandate” of our polytechnic education, which is to prepare graduates for the industry, as well as develop student’s competencies and practices of sustainable development. We feel that this contributes to the betterment of local/regional communities, as well as providing a more holistic approach towards engineering education in general.

EDUCATION FOR SUSTAINABLE DEVELOPMENT (ESD): A BRIEF OVERVIEW

The United Nations had designated 2005-2014 as the Decade of Education for Sustainable Development, giving due recognition that education is “the most effective means that society possesses for confronting the challenges of the future” (UNESCO, 1997). According to UNESCO, Education for Sustainable Development (ESD) aims to help people to develop the attitudes, skills, perspectives and knowledge to make informed decisions and act upon them for the benefit of themselves and others, now and in the future. ESD helps the citizens of the world to learn their way to a more sustainable future.

Over the years, although many higher education institutions around the world had responded to the challenge by including sustainable development in their curriculum, the progress had generally been slow. A recent UNESCO report noted that “much of current education falls far short of what is required”; and calls for a “new vision” and “a deeper, more ambitious way of thinking about education” (UNESCO, 2002). Sibbel (2009) attributed the non-attainment of ESD goals to the misplaced efforts in the past, on trying to change consumption behaviour, as well as limitations to relying on consumer action due to various barriers ranging from the very concept of sustainability to limits of human information processing capabilities.

There are now renewed calls for reinventing higher education (UNESCO, 2008; AASHE, 2010) using a whole systems approach (Waas et al., 2012) to address the issues of ESD. Shephard (2008) in particular, argued for the need to include affective domain in ESD, suggesting that “graduates should know about sustainability issues, they should have the skills to act sustainably if they wish to and they should have the personal and emotional attributes that require them to behave sustainably”.

However, there is no universal model of ESD; and nuanced differences according to local contexts, priorities and approaches exist even when there was overall agreement on the concept (De Rebello, 2003). Sterling (2004) identified a range of educational responses to sustainability as shown in Table 1, and advocated the third approach, which he termed “sustainable education.” This constitutes an order of learning higher than that of ESD. He explained the concept as one that is not just a simple add-on of sustainability concepts to the curriculum, but a cultural shift in the way we see education and learning, based on a more ecological or relational view of the world. Rather than a piecemeal, “bolt-on” response which leaves the mainstream otherwise untouched, it implies systemic change in thinking and practice, informed by what can be called more ecological thinking and values – essentially a new paradigm emerging around the poles of holism, systemic thinking, sustainability, and complexity.

Table 1. Three Levels of Education in relation to Sustainability

Education about sustainability	First-order learning Emphasis is on content/knowledge-based learning within the dominant paradigm Assumes that meaning of sustainability can be clearly identified and taught as a separate subject Essentially ‘learning as maintenance’ of current paradigm
Education for sustainability	Second-order learning Emphasis is on ‘learning for change’ that includes content, but goes further to include values and capability bias Deeper learning: involves critical and reflective thinking about sustainability Assumed that we know clearly what values, knowledge and skills ‘are needed’ for change and while challenging the existing paradigm leaves it mainly intact
Education as sustainability (Sustainable Education)	Third-order, transformative learning Emphasis is on process and quality of learning, which is seen as an essentially creative, reflective and participative process Knowing is seen as approximate, relational and provisional, and learning is continual exploration through practice Shift is towards ‘learning as change’ which engages the whole person and learning institution Process of sustainable development or sustainable living is essentially one of learning, while context of learning is essentially that of sustainability

Sterling (2004) further contended that the role of higher education “…should not be predicated only on “the integration of sustainability” into higher education, because this invites a limited, adaptive, response …we need to see the relationship the other way around – that is, the necessary transformation of higher education towards the integrative and more whole state implied by a systemic view of sustainability in education and society.” Vare and Scott (2007) further made the point that, “sustainable development, if it is going to happen, is going to be a learning process – it certainly won’t be about ‘rolling out’ a set of pre-determined behaviours”.

Our goal is to steer our education in chemical engineering towards the last type: third-order transformative learning where our students work closely with communities at the bottom of the pyramid to jointly formulate a workable solution for the people who needed help the most. In the process, we also hope to transform our students’ value and belief systems by directly engaging them in the process.

OUR APPROACH USING CDIO AS A CURRICULUM MODEL FOR ESD

We believe that our own approach towards curriculum re-design for sustainable development as presented below is unique in the sense that it is derived from the CDIO Framework, and customized for the needs of chemical engineering. The curriculum re-design process is therefore a structured and systematic one; and results from our CDIO implementation have shown that students found the learning process a meaningful and engaging one. Another unique feature is that it integrates chemical process design with chemical product engineering. The former is still the mainstay of chemical engineering education while the latter is newly emerging paradigm of the profession. This approach is consistent with the growing trend in chemical engineering education as we moved from a process-oriented curriculum which focused mainly on chemical plant design using modeling and simulation; to a more balanced approach incorporating product design as well. Most importantly, our curriculum model is able to serve the dual-purpose of (1) satisfying industry requirements with the necessary technical knowledge and soft skills (CDIO skills), so that the students are competent in the workplace; and (2) allowing them to serve the broader needs of society, especially those at the bottom-of-the-pyramid.

Figure 1 shows the curriculum model that had evolved over the last several years. It shows the key pillar of integrated process and product design approach of our chemical engineering education that builds on 3 modules taught across the 3-year curriculum, namely *Introduction to Chemical Product Design* (Year 1), *Chemical Product Design & Development* (Year 2) and capstone *Final Year Project* (Year 3). More details of our work in this area had been described elsewhere (Cheah & Ng, 2010; Ng & Cheah, 2012). Suffice to say that with this initiative, we had successfully integrated the CDIO skills of conceiving, designing, implementing and operating into our curriculum. The major outcome is that our students can come up with innovative chemical product and/or systems that meet the needs of sustainability during their capstone project, situated in the context of chemical engineering practices (Byrne & Fitzpatrick, 2009).

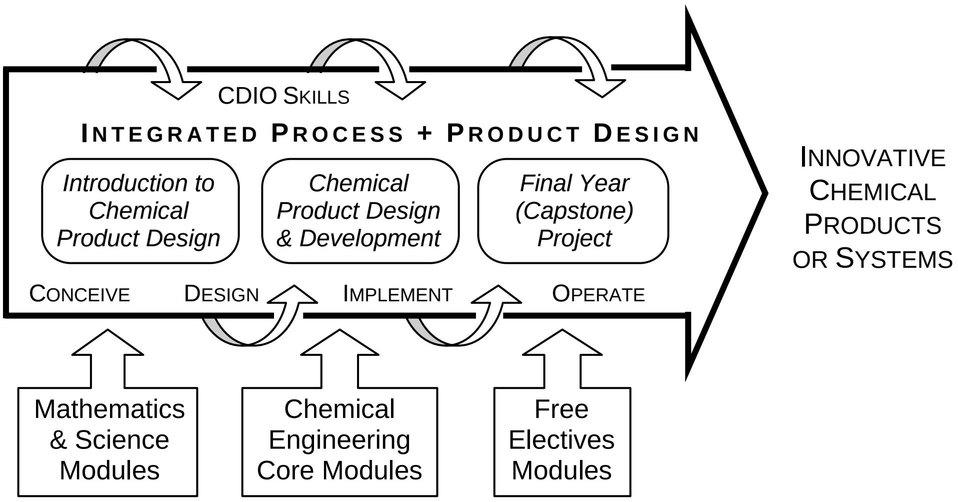

Figure 1. Chemical Engineering Curriculum Model for Sustainability Education

Supporting these 3 modules are the basic mathematics and sciences (chemistry, biology and physics), core chemical engineering modules (such as fluid mechanics, heat transfer, separation processes, and chemical reaction engineering), and a basket of free electives in Year 3.

We also carried out curriculum revamp in selected core modules to explicitly demonstrate how the various chemical engineering principles, besides their traditional use in process and equipment design, can also be applied to the serve the needs of sustainable development, in the form of innovative chemical products or systems. For example, our students learnt about chemical reaction kinetics and chemical reactor design, and in traditional chemical engineering design project will apply these in the design of a typical chemical processing plant. Now they also learnt about sustainability principles related to these topics, such as green chemistry and elimination of undesirable side-reactions, and the selection of greener reactions to support the goals of sustainable development. The pedagogical approach of integrating sustainable development into core chemical engineering modules had been described elsewhere (Cheah et al., 2012).

Also shown in Figure 1 is the integration of various CDIO skills (shown as curved arrows) such as teamwork and communication, critical and creative thinking, systems thinking, ethics, global mindset, etc into core modules in our curriculum. These are the same skill sets identified as important in ESD (Svanstrom, et al., 2008). Such integration efforts are all carried out using the context of chemical engineering practice and had been described in various papers at past CDIO conferences (see for example: Cheah, 2009; Yuen & Cheah, 2012; Yau et al, 2013). This model embraces the inclusion of ethical issues and multiple perspectives – both aspects which had been identified as lacking in the original “overlapping circle” sustainable development model (Burns, 2011; Vucetich & Nelson, 2010). In addition, it also captures other skills not mentioned or explicitly identified in other curriculum models on ESD, including lifelong learning, product lifecycle analysis, global mindset, etc.

Our model therefore emphasize not just on students being able to integrate their technical knowledge into their projects, but also for them to demonstrate understanding in considering social and economic aspects of sustainable development as well.

Our notion of “chemical products or systems” refers to that of “technology that uses chemical engineering principles” by Shaeiwitz & Turton (2003), which we felt is more appropriate for the outcomes expected of our diploma-level students as compared to the four categories as initially defined by Cussler & Moggridge (2001), viz:

- New specialty chemicals
- Products whose microstructure rather than molecular structure creates value (e.g. paint)
- Devices causing chemical change (e.g. a blood oxygenator or the electrolytic device)
- Virtual chemical products (e.g. software to simulate chemical processes or estimate physical properties)

We also clarify “innovative” outcome of our approach to mean engineering products and systems that are driven by social, environmental or sustainability issues; and add values to the community-in-need. In other words, anything that is new to the community is counted as innovation, even if similar products are available elsewhere or if the change is an incremental one. Some of these innovative products that came out from the capstone projects include waste-to-gas digester, seaweed-to-fertilizer, rain water harvesting system, insulation material from sugarcane bagasse, pedal-powered filtration unit, and floating toilet system. Some of these projects had been implemented or in process of being implemented, both locally in Singapore and in various countries in the region, including Indonesia, Myanmar, Nepal and Cambodia.

Figure 2 shows two other related applications that we found useful to complement the conceive-design-implement-operate process for our model of ESD – design thinking and appropriate technology. These 2 topics are further explained below. Firstly, our experience in using design thinking had indicated that it is a useful tool to complement the “C” (conceive) and “D” (design) stage of CDIO (Chua & Cheah, 2013), and had in fact, introduced it in Year 1. The design thinking approach (Brown, 2009) focuses on three mutually supporting elements, namely that of user empathy (“What is desirable to users?”), technical feasibility (“What is possible with technology?”) and business viability (“What is viable in the marketplace?”). Dos Santos Martins (2010) had suggested that design thinking is needed to identify the root cause of sustainability-related problems; because these problems are not easy to define, and hence are “wicked” in nature (Rittel & Webber, 1973). 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. Several other authors had also written about the importance of design and design thinking in sustainable development (Wahl & Baxter, 2008; Young, n.a.).

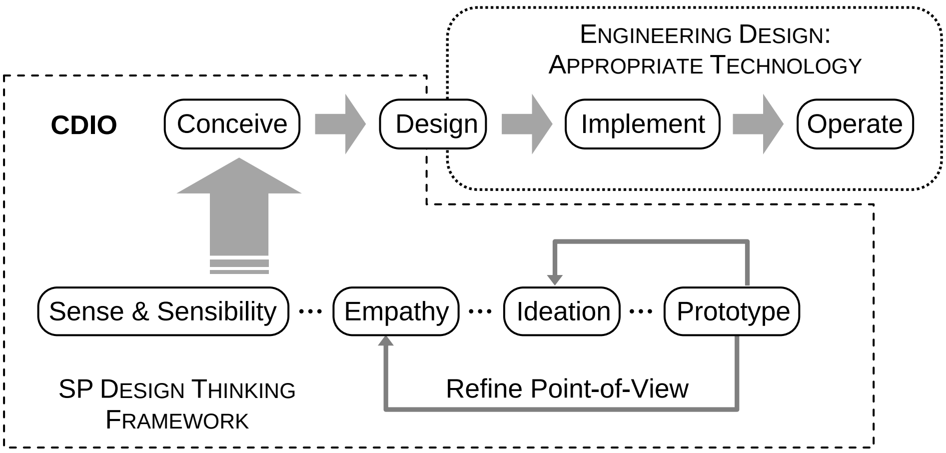

Figure 2. How Design Thinking and Appropriate Technology support phases of CDIO

Secondly, we suggested the use of appropriate technology to drive the “I” (implement) and “O” (operate) phases of CDIO – in delivering innovative chemical product design envisioned in our curriculum outcome. Appropriate technologies – a term attributed to Schumacher (1973) – are usually characterized as small scale, energy efficient, environmentally sound, labor-intensive, and controlled by the local community (Hazeltine & Bull, 1999). The core principle of appropriate technology is to include local communities in technology selection and development, innovation and implementation, all in an environmentally sustainable manner (Tharakan, 2006). Appropriate technologies are often perceived as “low tech” and unimportant, and not usually addressed in engineering education or university research (Sandekian et al.,2007). 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; and yet they can be empowered to actually design and implement a workable product or system, consistent with the needs of the poor at the bottom of the pyramid, and the goals of sustainable development. A high self-efficacy in students has been identified by Wals and Jickling (2002) as one of the important outcomes of ESD.

The incorporation of design thinking also helped to inject some elements of creativity into the use of appropriate technology to attain sustainable development goals. This is best summed by Schumacher (1973) 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."

Wahl and Baxter (2008) are even more explicit, when they noted that "sustainability is a process of co-evolution and co-design that involves diverse communities in making flexible and adaptable design decisions on local, regional, and global scales."

Figure 3 shows how the three circles of design thinking can be "mapped" directly to the three circles of sustainable development. While it is arguable if innovation can only result from the intersection of all 3 circles of user empathy, business viability and technical feasibility as implied by the Venn diagram; this model of innovation is the one adopted institution-wide, and as such, we retain it in this work. We recognised that other models are available and that innovation can occur without all three circles intersecting. Besides, we feel that such mapping helps us to focus our ESD curriculum design better, and it aids our communications to our students so that they can better see the relevance of the design thinking model in relations to what they are taught in applications of chemical engineering principles to sustainable development.

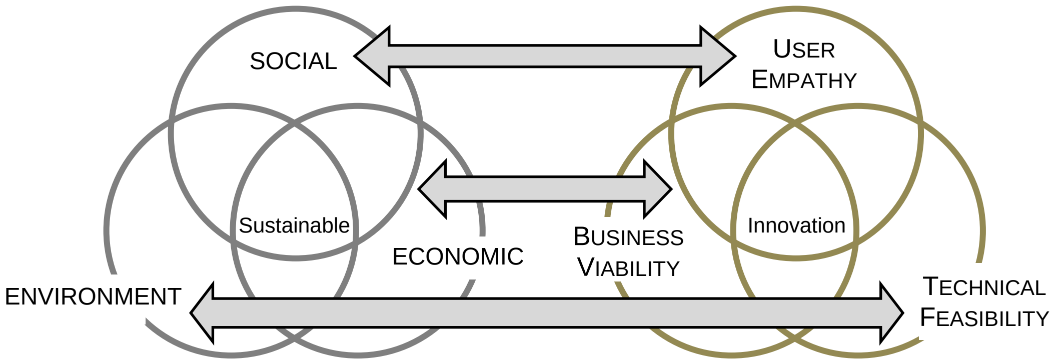

Figure 3. Mapping between Design Thinking and Sustainable Development

Nagel et al (2012) had earlier suggested that both 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. With such a mapping, we wished to avoid the problem highlighted by a number of authors whereby the coverage of sustainable development at some institutions had narrowly focused only on environmental issues (Kagawa, 2007; Segalas et al, 2010).

Our model of ESD hence allow us to directly engage students in all three aspects of cognitive (head), psychomotor (hand) and affective (heart) domains of learning that will allow transformative learning to occur (Sipos et al., 2008). Elliott (2010) noted that signs of change among students who learnt in this manner can be observed by shifts in their attitudes, values and behaviors. Indeed, conversations with our students who took part in various capstone projects of such nature seemed to support the attainment of desired learning outcome of ESD (Chua & Cheah, 2013). However, it is probably too early to tell if long-term changes in students' attitudes, values or behavior had indeed taken place as we have not yet carried out any formal study on the impact of such curriculum re-orientation.

DISCUSSIONS

Using the curriculum model of ESD above, our students had, over the past few years, generated many interesting ideas and projects – both realizable and not. For the handful of projects that were successfully implemented, there are many others which did not make it to the next stage of development. Therein lies the major challenges of introducing product design into chemical engineering curriculum. It had to be expected that not all ideas will translate into products; and not all products can be realized at diploma-level competency. One example is the portable oil skimmer project which resulted in a workable prototype but is hard to scale-up for a reasonable-level of real-world application.

The time duration available for students to work on their *Final Year Projects* is also a key factor, as students need to balance their project work alongside the demand of other modules and examinations. We are also mindful that the assessment mechanism must incorporate both "process" and "product" components when evaluating students' work; and that a fully functional prototype is not always achievable within the project timeframe. For students whose project ideas did not get past Year 2, we had to depend on our lecturers coming up with suitable projects doable within one year, so that no students will be left without a project when they reach Year 3.

Another related challenge is that of project continuation by the next group of *Final Year Projects* students, who may be performing tasks in project execution that are considerably different from those of the first initiating group, such as optimizing the design, or carrying out on-site troubleshooting. A "one-size-fits-all" assessment scheme clearly is not suitable for *Final Year Projects* of such nature, and we need to explore the feasibility of having customized assessment schemes in view of additional work demanded from such an endeavor. We also need to have evaluations that go beyond the "has it been learnt?" questions to capture unforeseen "what has been learned?" outcomes, and "how do we know?" enquiries as further sources of learning (Vare & Scott, 2007).

We also identified other issues and challenges related to chemical product design engineering and these are briefly explained below:

<u>Scaling-up</u>: Hermann (2007) noted that the adoption of a more holistic approach to education for sustainability is also likely to demand that consideration be given to the environment in which students engage in the learning process. We certainly want to introduce our students to more out-of-classroom learning, which will make the learning process more authentic; an approach that had been proven to be more engaging and resulted in enhanced learning. Currently our approach involved only several groups of students in their *Final Year Projects*, numbering around 6-9. We need to extend the experience to the rest of the cohort of students. This presents challenges in not just getting enough sustainability-themed projects for them to work on, but also sufficient number of local communities to accommodate them all.

Puukka (2008) suggested that sustainable development can best be mobilized by higher education in the context of regions by developing strategic partnerships between institutions. We already have some projects overseas, and this approach can "alleviate" the problem we faced above – to a certain extent. Going regional also offers the advantages of opening our students' eyes to the needs of the regions. Being a relatively affluent society, our students had grown up in relative comfort and henceforth failed to appreciate the need for sustainability. While plausible, going regional can still be prohibitive cost-wise, and the number of such student groups are still relatively small. Concern from parents over the "hardships" on their children is another factor we need to contend with. To overcome this, we will consider organizing a parents' seminar where students who went on such overseas trips can share the benefits with the parents to generate greater buy-in.

Logistics: Related to the above, to engage a large number of students in out-of-classroom learning poses logistic challenges in terms of transport, outdoor classrooms, and other amenities. Timetabling for such activities is another challenge that may not be easy to overcome; especially when faced with lesson cancellation due to public holidays. The logistical burden will also be heavier for projects based on overseas locations. As such, all our current trips are planned for during the vacation, which posed a different set of problems in terms of getting enough staff to sacrifice their holidays to accompany students on such trips. We are currently looking into ways to compensate our staff in this area.

CDIO skills coverage: At the moment, certain skills such as systems thinking and lifelong learning are not sufficiently covered in the 3-year curriculum. Others, such as ethics, while adequately covered, are not directly linked to sustainable development. There is a need to explicitly make this connection. Ethics is also related to an individual's value system, cultural beliefs and norms, etc. Value education and teaching of cultural sensitivities undoubtedly will pose challenges as well. We are currently working with a partner university in Vietnam to allow our students to complete an e-learning module offered by the university prior to them embarking on the overseas trip to Vietnam.

Multi-disciplinary approach: Our endeavor thus far involved only our own students. Involving them working together with students from other disciplines will certainly enhance the learning process. O'Rafferty (2011) for example, had argued that inter-disciplinarity is a necessary requirement for addressing sustainability issues. Likewise, Czippan et al (2010) made the case that for ESD in an institution to be sustainable over time, the efforts should be reflected in the very culture and mission of the institution, which requires the various disciplines to work closely together. Given the scale-up and logistics issues mentioned above, 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. We are currently embarking on a institution-wide initiative to re-structure our diploma program to free up more curriculum hours. We hope that this will enable students from different discipline to come together to work on projects.

Assessment: Last but not least, is the issue of assessment. Shephard (2008) had noted that "…it is quite possible for learners to learn about their subject and be able to describe, comprehend, apply, analyse, synthesise and evaluate to the extent that they can pass their exams, without actually changing their attitudes as indicated by the way they respond or behave afterwards." At this point, we do not have in place an assessment format to validly and sufficiently assess the affective domain of ESD beyond some anecdotal evidence articulated by students during informal conversations. This is certainly an area that we will address in the near future.

More importantly, from the learning point of view, we are not compromising on students gaining real-world technical know-how needed for their future employment. The main emphasis of our curriculum is still to equip students with real-world attributes desired by employers. The initiative of ESD is to complement the cognitive domain with affective domain; both of which are increasingly important in today's complex world.

CONCLUSIONS

In his book, *Out of Our Minds*, Sir Ken Robinson (2011) noted that education has three core purposes: (1) Personal – to develop students' individual talents and sensibilities, (2) Cultural – to deepen their understanding of the world around them, and (3) Economic – to enable them to earn a living and be economically productive.

We have outlined an approach used to design a curriculum that integrates sustainable development in the chemical engineering context. Using this model, we have provided our students with the knowledge that not only satisfy the "traditional mandate" of our polytechnic education, which is to prepare graduates for the industry (the third goal above), but also to enable them to "do good" by contributing to the betterment of local and/or regional communities (the first and second goals). We believe this model is also adaptable to other engineering disciplines.

However, the journey is far from over. There are still many challenges to overcome and not-yet-obvious issues to resolve. The words from Scott (2002) are most apt in this regard:

> "Just how what we do affects (and helps effect) development towards sustainability remains an open question, and more research is needed to help model our understanding of how education can contribute to sustainable development …."

One may curiously note that we use the term "education for sustainable development" for the title of this paper, which represents only a second-order learning (Table 1) in terms of the role of education in sustainability. This usage is intentional – it represents our current effort in the development of a curriculum model for sustainable development which recognizes that we have not sufficiently attained the aim of third-order learning, i.e. that of "Sustainable Education". We believe that our model, grounded in the CDIO approach that explicitly seeks to integrate sustainable development in the context of engineering practice, can be further refined to continue with our quest in this important area.

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