PEDAGOGICAL APPROACH TO INTEGRATE SUSTAINABLE DEVELOPMENT INTO ENGINEERING CURRICULUM

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ABSTRACT

The Diploma in Chemical Engineering (DCHE) course of Singapore Polytechnic (SP) adopted the CDIO framework as the basis for its curriculum since 2007. Over the last several years, under the guidance of the DCHE Course Management Team (CMT) specific CDIO skills have been introduced in various core modules in the 3-year diploma program. A range of Interpersonal Skills, such as teamwork and communication, and Personal & Professional Skills are now established curriculum components.

This paper focuses on the integration of sustainable development into the chemical engineering curriculum for a core module entitled *Chemical Reaction Engineering*, taught to Year 2 students. It firstly presents an overview of sustainable development, and summarizes current approaches to sustainable development in the chemical engineering curriculum, including pedagogies and tools more specific to chemical engineering.

Secondly, we present our experience in designing learning tasks to facilitate student understanding of sustainable development, and how we have subsequently revised the type of tasks based on student feedback (via survey questionnaire and focused group discussion) of their learning experiences.

The paper concludes with our present frame on how to enhance the student experience of learning about sustainable development, both in this particular module and the diploma in general. For example, the integration so far has focused mainly on two of the three “triple bottom lines” of techno-centric concerns and eco-centric concerns. We will share a new initiative that attempts to engage students in all aspects, with special emphasis on the “missing link” of socio-centric concerns.

(NOTE: Singapore Polytechnic uses the word "course" 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”.)

Keywords: Sustainable Development, Sustainability, Chemical Engineering, Curriculum Integration

INTRODUCTION

This paper focuses on the integration of sustainable development into the chemical engineering curriculum for a core module entitled *Chemical Reaction Engineering*, taught to Year 2 students of the Diploma in Chemical Engineering (DCHE) students from Singapore Polytechnic (SP). As we had been using CDIO as the basis of re-designing our curriculum for the past several years, we naturally based our current effort using the revised CDIO Syllabus version 2.0 Section 4.1.7 “Sustainability and the Need for Sustainable Development” [1] which suggested the coverage of the following topics:

- Definition of sustainability
- Goals and importance of sustainability
- Principles of sustainability
- Need to apply sustainability principles in engineering endeavours

WHAT IS SUSTAINABLE DEVELOPMENT?

The most common definition of sustainable development is that of the Brundtland Report published in 1987 which stated that "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [2]. Following this, in 1992 at the Earth Summit in Rio de Janeiro, Agenda 21 which is a global action plan for delivering sustainable development, was adopted. A key feature of it is the statement that “education is critical for promoting sustainable development and improving the capacity of the people to address sustainable development issues” [3].

Over these decades, the definition of sustainable development evolved. The core of mainstream sustainability thinking has become the idea of three dimensions, environmental, social and economic sustainability. These have been drawn in a variety of ways, as “pillars”, as “concentric circles”, or as “interlocking (or overlapping) circles” [4]. The most commonly accepted notion of sustainable development is that of the overlapping circles that constitute the “triple bottom lines”, depicted in Figure 1 below:

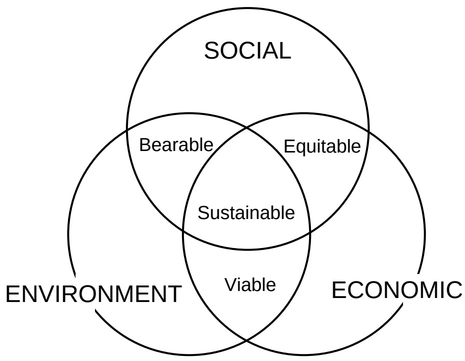

Figure 1. General representation of sustainable development

In 2005, the United Nations (UN) declared a decade (2005-2014) for Education for Sustainable Development (ESD). The UN’s aim here is to challenge global educational policymaking by highlighting the global significance and importance of ESD, and actively encouraging the coordination and dissemination of best practices [5].

CHALLENGES IN TEACHING SUSTAINABLE DEVELOPMENT

From the above, it is clear that education has been identified as the primary vehicle for sustainable development. While useful at the conceptual level; the "definition" is however not very useful for academics in teaching sustainable development to engineering students. In fact, a plethora of definitions existed for the terms "sustainability" and "sustainable development" [6]. Embedded in the "definition" of sustainable development is the need to achieve many things. Clift [7] for example, noted that "although sustainable development is invoked in current political and environmental debates, the concept has eluded precise definition." Also, noted Adams [4]: "… one reason for the widespread acceptance of the idea of sustainable development is precisely this looseness ….. The idea of sustainable development may bring people together but it does not necessarily help them to agree goals. In implying everything sustainable development arguably ends up meaning nothing."

Martin et al [8] argued that "In general, the subject disciplines were reluctant to adopt any particular definition because they felt that it compromised important aspects of how they approached the subject. Within the humanities field there was a strong reluctance to apply any of the existing definitions, because they arose mainly from the environmental, social and political sciences and gave limited emphasis to the concept of 'equity' and 'empowerment'. Other disciplines argued that definitions could mask diversity and stifle debate because broad definitions can cover up differences and give an illusion of consensus. Some subject disciplines were content to use the Brundtland definition, whereas more applied fields preferred more utilitarian definitions."

More recently, Boyle [9] noted that "the basic concept of sustainability as defined by the WCED requires an understanding of human and societal needs and the environment and its limitation, as well as a context of time and future. Thus, sustainability requires an understanding of complexity and systems far beyond that taught in traditional engineering programmes". He further noted that "although there had been a consensus among professional engineering associations that sustainability is important to engineers and that they have to take it into account in their professional practice, there had been no agreement on how this is to occur. Many educational engineering institutions are moving to incorporate sustainability engineering into their curriculum but each institution has its own interpretation of sustainability engineering and its applicability within an education programme."

Henceforth, the education for sustainable development continues to remain a challenge. As noted by Schumacher [10], long before the word sustainable development came into vogue:

> "The volume of education ... continues to increase, yet so do pollution, exhaustion of resources, and the dangers of ecological catastrophe. If still more education is to save us, it would have to be education of a different kind: an education that takes us into the depth of things."

Also emphasising the need for a new kind of education, Sterling [11] maintained that the nature of sustainability requires a fundamental change in epistemology and, therefore, in education. Indeed, Thom [12] proclaimed the adjustments required are so fundamental that they are driving a paradigm shift. Likewise, Byrne and Fitzpatrick [13] noted that "A new paradigm is required … whereby sustainability becomes the context of engineering practice. A sustainability informed ethos must prevail throughout engineering curricula."

However, Batterham [14] commented that "progress on moving towards sustainability embedded curricula can be slow however; even universities to the forefront in terms of embracing sustainability over the past two decades have faced substantial difficulties, not least due a narrow conception of sustainability among faculty."

Teaching sustainable development henceforth requires not just new tools but a new role. For the engineering discipline, this means that those with engineering expertise need to contribute at an early stage in the framing of problems, not just in problem solving, i.e. engineers should have a normative role as well as their more familiar analytical role [15].

As aptly captured by Splitt [16]: "The transition from the old to the new paradigm will not be easy …. the wherewithal to make the changes rests mostly with those who oppose the change in the first place. This situation, coupled with the fact that there is no 'one-size-fits-all" transition paradigm, represents the challenge to change." This is consistent with the old adage that "Engineers are always on tap, rarely on top. Engineers are there to solve problems defined by others, along with imposed constraints on the solution, but not to set the agenda for problems to be solved."

SUSTAINABLE DEVELOPMENT AND CHEMICAL ENGINEERING

The chemical engineering profession, led by the Institution for Chemical Engineers (IChemE) UK, for its part, had staked its position to support sustainable development following the Melbourne Communiqué [17]:

> We, the representatives of twenty organizations representing chemical engineers world-wide, subscribe to the following statement: "Entering the Twenty-First Century, we in the chemical engineering profession renew our commitment to using our skills to strive to improve the quality of life, foster employment, advance economic and social development and protect the environment through sustainable development."

The IChemE included the mandatory coverage of sustainable development in its accreditation guide for chemical engineering programs. An illustration of the generic Bachelor-level learning outcomes for sustainable development in economic, social and environmental context is as follows [18]:

- Knowledge and understanding of commercial and economic context of chemical engineering processes
- Knowledge of management techniques which may be used to achieve chemical engineering objectives within that context
- Understanding of the requirement for chemical engineering activities to promote sustainable development
- Awareness of the framework of relevant legal requirements governing chemical engineering activities, including personnel, health, safety, and risk (including environmental risk) issues
- Understanding of the need for a high level of professional and ethical conduct in chemical engineering

The IChemE noted that chemical engineering is presented with "a moment of opportunity" to tackle the issue of sustainable development [19] and listed sustainability as one of the six priority topics of focus in its Roadmap for 21st Century Chemical Engineering [20].

The chemical engineering community had explored how best to teach sustainable development in its curriculum. Byrne [21] suggested that sustainable development be integrated into the engineering curriculum. He noted "sustainability will be the context within which engineering is practiced throughout the 21st century and beyond. The integration of sustainability into engineering programs will broaden the perspective of the profession and fundamentally re-evaluate its role within and responsibilities towards society. This offers the potential to reinvigorate the profession as engineers perceive a more central role in making a positive contribution to society."

Exactly how the integration is practiced varied from different chemical engineering programs. Davis [22] highlighted that there is a clear distinction between education *about* sustainable development and education *for* sustainable development. The former simply implies an awareness of the issues and the ability to discuss them in context, while education *for* sustainable development implies not simply an understanding of the issues, but an ability to apply, design and operate systems that are sustainable.

Huntzinger et al [23] reviewed various models that offered teaching of sustainable development in engineering curriculum and reported that three general models were practiced, as noted in Table 1.

Table 1.
Different way to integrate sustainable development into curriculum

Mode	Meaning
Bolting-on: Education about sustainability – An "add-on" strategy	Awareness; separate courses about sustainability
Reformation: Education for sustainability – A "built-in" strategy	Critical reflection on and in action; integrating sustainability issues in regular disciplinary courses
Transformation: Education as sustainability – A "re-build" strategy	Questing, contextualizing and negotiating and integrating the concept of sustainability; paradigm shift and learning as change

The highest form of integration according to this table is the "re-build" strategy. Martin [24] explained this as building the "sustainability literacy" of our graduates; by understanding how human actions affect the immediate and long-term future of the economy and ecology of our communities; and by developing the necessary knowledge and skills, we can to change to a more sustainable way of doing things, both individually and collectively.

THE DIPLOMA IN CHEMICAL ENGINEERING APPROACH

Sustainable development is covered in the SP-customized CDIO syllabus, Section 4.1 External and Societal Context as follows:

4.1.1 Understand Roles and Responsibility of Technologists
Explain professional goals and roles of the engineering profession
Analyze the responsibilities of technologists to society

4.1.2 Understand the Impact of Engineering on Society
Explain the impact of engineering on the environment (e.g., ecological, social, economic, cultural systems etc)
Explain the need for Sustainable Development
Identify possible solutions to support Sustainable Development

For our diploma program, we adopted the model of sustainable development as shown in Figure 1. We then specifically look into what sustainable development means in the context of chemical engineering at the diploma level, and turned to our tried-and-tested approach that infuses CDIO skills (e.g. teamwork, communication, critical and creative thinking etc) into our curriculum to integrate the learning of sustainable development [25, 26].

In discerning what sustainable development means to chemical engineering, we asked the same question posed by Crawley et al [27]:

- What is the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?
- How can we do better at ensuring that students learn these skills?

For the former we look to the view of sustainability as articulated by the American Institution of Chemical Engineers (AIChE): "a path that should be followed in providing technological solutions to societal problems as well as all engineering processes and product design and development" [28]. With this approach, we focus our effort on applying chemical engineering principles to sustainable development that involves the design and management of sustainable technology, research into environmental and social impacts and limitations while living within those limitations, and management of resources from cradle to cradle." [9]

Various authors have suggested how chemical engineering principles can be applied in sustainable development. For example, Fan et al [29] noted that "Chemical engineering has three core concepts that are essential to the implementation of sustainability: systems thinking, material and energy balances, and the use of metrics for total costing approaches." Jan Venselaar [30] suggested three main areas for chemical engineering: product development and application, process intensification, and biomass resources.

Our present approach is that of "built-in" strategy (Table 1), based on the model that we used to integrate various CDIO skills in to the curriculum, shown in Figure 2.

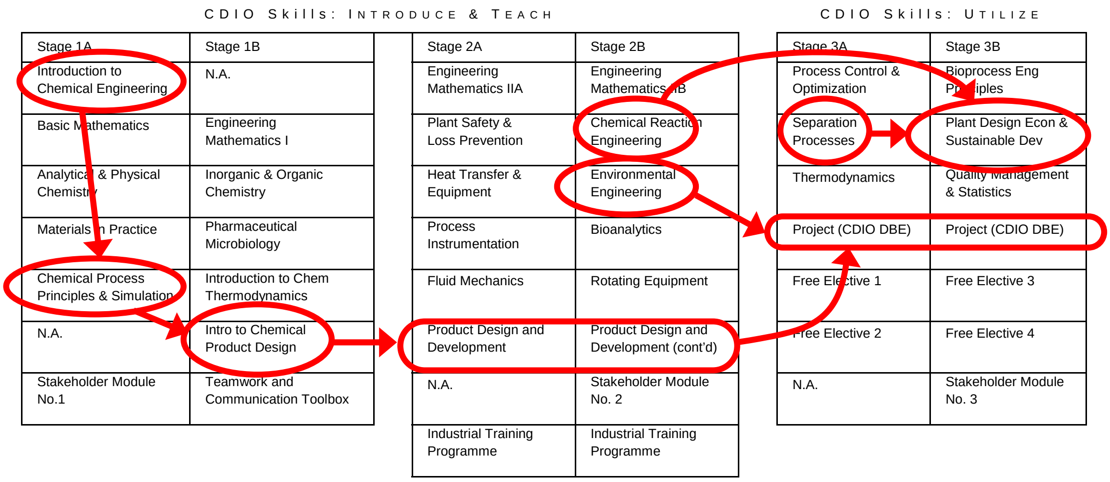

Figure 2. Model for integrating CDIO skills across DCHE curriculum

Segalas et al [31] reported on their a 5-year research project involving more than 5,000 students from five European universities which conclude that using a more community-oriented and constructive, active learning pedagogical approach increased students' knowledge of sustainable development. They also compared the contribution of different pedagogical strategies to the education of sustainable development. Other authors have proposed more specific pedagogic approaches: for example, problem-based learning (Garland et al [32], Steinemann [33]), case study (Davis [22], Glassey [34]). It is envisioned that we will be using an entire *potpourri* of pedagogies.

Selected core modules from the diploma where sustainable development are built in are shown in Table 2 below.

Table 2
Core modules where sustainable development are taught

Year 1 Awareness	Year 2 Reinforcement	Year 3 Application
Introduction to Chemical Engineering: Responsible Care as part of responsibility of the procession *Introduction to Chemical Product Design*: Concept of sustainability using detergent as example *Chemical Engineering Principles & Simulation*: Atom Economy, "Green" material balance *Introduction to Chemical Thermodynamics*: Use of fuel cell as source of clean energy	*Chemical Reaction Engineering*: "Greener" reaction pathway, waste minimization, reactor design, alternative fuel *Environmental Engineering*: Systems thinking: impact of engineering on environment, carbon footprint, environmental impact assessment *Product Design & Development*: Lifecycle analysis, systems thinking: impact of engineering on society *Heat Transfer & Equipment*: Heat exchanger network and heat integration	*Separation Processes*: Solvent selection, distillation vs membrane systems *Plant Design, Economics & Sustainable Development*: Process selection, materials of construction, raw materials, waste generation, process intensification, biomimicry *Final Year Project*: Solution evaluation and selection, material selection, disposal option (e.g. recycle vs landfill vs incineration)

With this approach, we hoped that students will be able to, when they work on their Year 3 *Final Year Project*, apply what Parkin et al [35] referred to as the "at the same time rule", that is "Students should be able to analyse issues and choices from an environmental, social and economic perspective at the same time, rather than separately. Even though decisions might be about specific matter, such as the purchase of a piece of equipment, a sustainability literate person would be able to evaluate the available options, from the perspective of its positive or negative long-term effect on a financial budget, on people and on the environment (p.18)."

The following section focuses on the actual work done for a specific core module, entitled *Chemical Reaction Engineering*, taught to Year 2 students.

DISCUSSION OF WORK DONE TO DATE

The module *Chemical Reaction Engineering* is the first module in the curriculum that was revamped using CDIO [36, 37]. Consistent with past integration efforts, we used the student-centred approach to curriculum design by Felder and Brent [38] (see Figure 3) to integrate sustainable development into the module.

The learning objective is to encourage students to understand how chemical reaction engineering plays a role in attaining the goal of sustainable development in the chemical industry. Hence, in Semester 1, Academic Year 2010, we first introduced a case study as one of the module's learning activities. The case study requires students to investigate the use of suitable bioreactor for bioethanol production. Students were required to compare and contrast the bioreactor with traditional chemical reactors (i.e. those using synthetic chemicals as feed materials); as well as to evaluate the use of various food sources as feedstock and explore how to make the process more sustainable in the longer run.

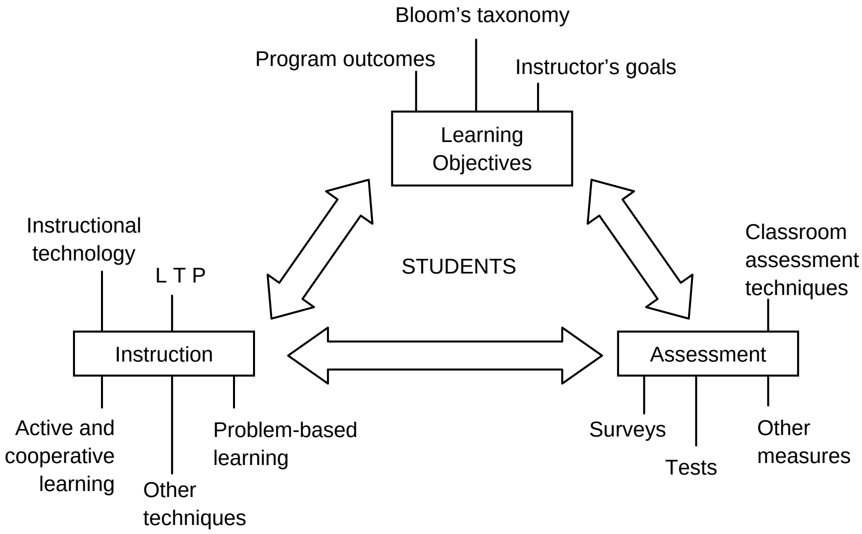

Figure 3. Student-centred approach to curriculum design

We conducted a questionnaire survey of which 47 students responded. We asked them on their understanding of the concept of sustainable development, challenges they faced when researching on the topic and attitude towards sustainable development, and if they agree that it is important for chemical engineering students to learn sustainable development. We also conducted a focused group discussion with selected students. From the survey results, more than 85% of the students agreed that it is important, as shown in Figure 4 below.

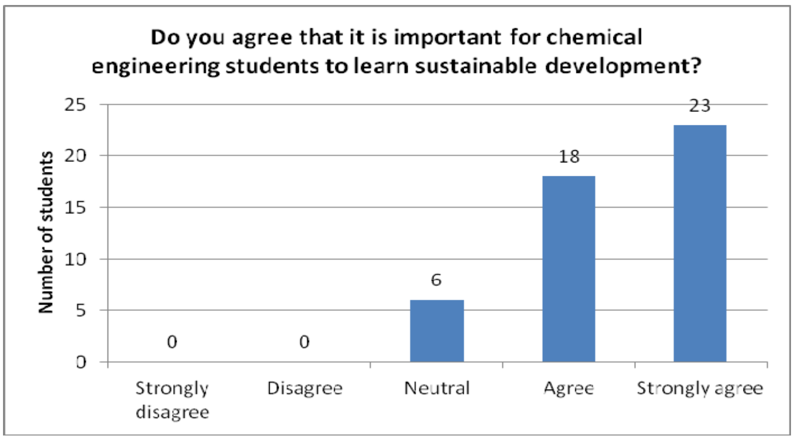

Figure 4. Student responses regarding the importance of learning sustainable development

The results showed that while most students had a good understanding of the concept of sustainable development (having learnt of the concept in another module entitled *Environmental Engineering*), many do not perceive it as a major concern to them as students at this point in time. The following student responses illustrate the typical framing:

> "It doesn't affect me at current and I've never thought of it before."

> "I did not see the need of researching about sustainable development."

> "I can't do a change because I don't have the authority. I'm limited with what I can do now – you can make a bigger difference if you have the authority."

This is perhaps not too surprising, as other authors had previously reported on the lack of appreciation among university students on this subject. Most telling is Azapagic et al [39], who surveyed 3,134 engineering students across several disciplines, from twenty-one different universities in nine different countries, and found that overall the level of knowledge is not satisfactory and that significant knowledge gaps exist.

From those students who ‘strongly agree’ that it is important to learn sustainable development, one of them commented that “Traditional chemical engineering promotes technology that pollutes the environment and seldom have sustainable methods in production. Hence, we should learn the importance of sustainable development to ensure continuity of resources”.

Another student commented that “It is partly our responsibility as future chemical engineers to focus on the issue of sustainable development and to maximize or preserve our resources for future generations”. One of the students who ‘agrees’ that it is important to learn sustainable development commented that “rather than teaching later, it is better to instill such idea from young so that we grow up and will be able to apply the knowledge”.

In terms of the student learning experience in the learning tasks set, some indicated that the concept did not come across strongly in the activity they performed, nor were they able grasp how it can be related to chemical reaction engineering. This is reflected in the survey responses of 56 students, as shown in Figure 5 below. Approximately 41% of the students agreed that the learning task exposed them to the idea of sustainable development, while 12% of them disagreed. The remaining 47% was neutral.

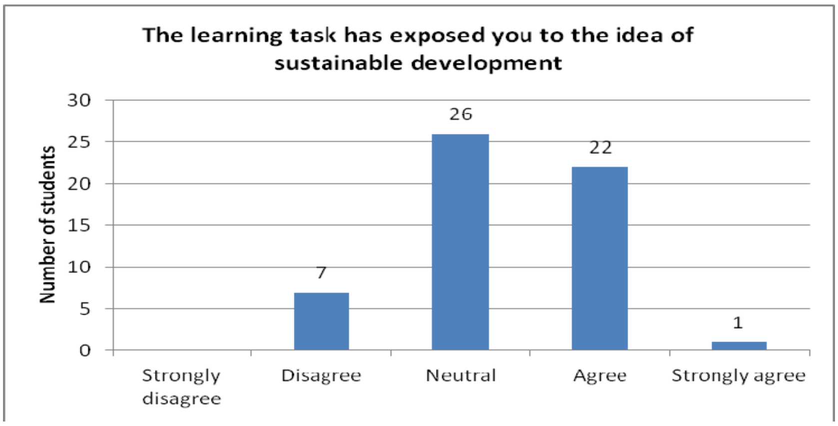

Figure 5. Student responses regarding the exposure of sustainable development in the learning task

The main reasons for this relatively low impact experience may also not be too surprising. For example, as Boyle [9] noted, there are many challenges: maturity of students, knowledge of sustainability among lecturers, lack of textbooks, lack of examples and lack of time. We certainly could not agree more!

On our part, we felt that we had set the “wrong” learning activity in that it focused more on students learning of the bioreactor as an end, rather than using bioreactor as the means to an end, which in this case, should appropriately be its role is sustainable development. We were hoping that through the study of characteristics of bioreactors, one of which is bio-based feedstock, students can appreciate the use of renewable materials, and hence better understand the role of chemical reaction engineering in promoting sustainable development.

We, therefore, re-conceptualized the learning approach and with input from the focused group, introduced a new activity in Semester 2 Academic Year 2011. In this revised case study, we require students to specifically investigate a chemical process that produces ethyl acetate, a common industrial solvent. One of the many ways this can be achieved is using ethanol as the raw material. Ethanol can now be produced in a sustainable manner using biomass resources.

Post the student experience in the revised activity, we conducted a further survey and found that some 60% of the students felt that this task is more effective in exposing them to the idea of sustainable development, as shown in Figure 6 below. This indicated that the new approach was more effective in enabling students to link the concept of sustainable development to chemical reaction engineering.

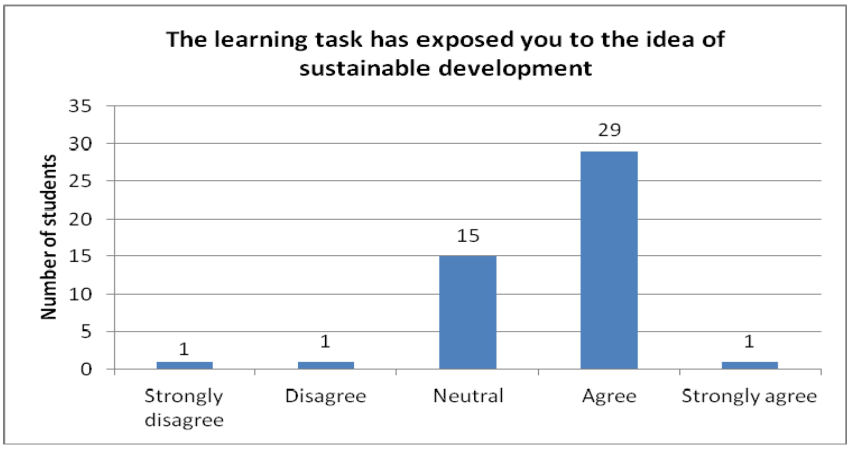

Figure 6. Student responses regarding the exposure of sustainable development in the revised learning task

Approximately 50% of the students agreed that chemical reaction engineering plays an important role in promoting sustainable development in the chemical industry, while another 50% remained neutral about it. Furthermore, from the students' reflective journals, the evidence reinforces a view that the new activity was much better received. The following examples from the journals are typical of the responses:

> "This practical have enabled me to inquire the knowledge about sustainable development. It also stimulates us to think about other alternatives to produce a product in an environmentally friendly way. For example, by using chemical reaction engineering, I have learnt that there are other methods to produce ethanol to manufacture ethyl acetate. One of the methods is ethanol dehydration."

> "Current chemical processes depend most heavily on non-renewable fossil-based raw materials which are definitely unsustainable in the long run. To make such processes sustainable, chemical technologies must indeed focus on employing renewable raw materials as well as minimizing or preventing pollution caused by such processes."

> "During this activity, my team has learnt the importance of sustainable development in chemical reaction engineering. Production of chemicals can be done using alternative feedstock such as biomass, instead of conventional feedstock that are derived from sources such as crude oil, that harms the environment and are not sustainable. Apart from using feedstock from sustainable resources, technology involved in production can be made sustainable such that it involves less stages of processing and less energy used. This will ensure that resources are sustainable to

meet the needs of the present without compromising the ability of *future generations* to meet their own needs. Otherwise, the depletion of non-renewable sources would certain pose a big problem to the future generations."

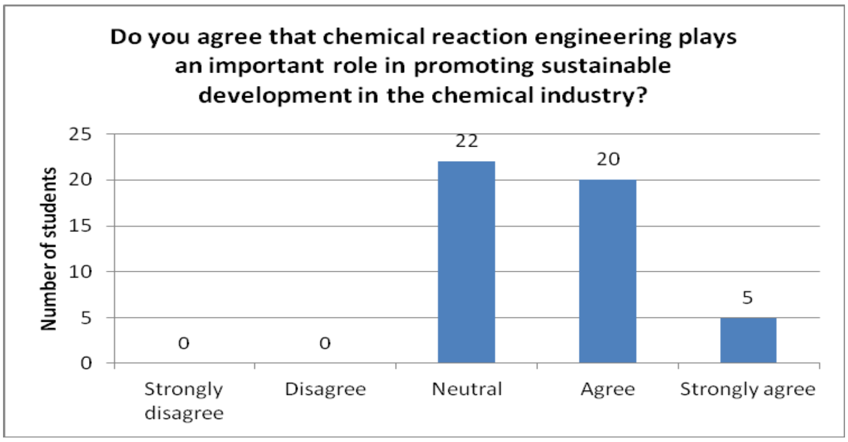

Figure 6. Student responses regarding the importance of chemical reaction engineering in promoting sustainable development in the chemical industry

"The practical on the sustainable development via Chemical Reaction Engineering has given me another perspective towards chemical engineering. Chemical engineers play an important role in sustaining the environment by developing advanced operating methods/equipments to replace conventional means which could harm the environment. An excellent example would be the manufacturing of fuels using crops. By using crops to produce fuel, it cuts down on the carbon emission, reduce the use of fossil fuels and most importantly, creating a sustainable method for fuel production. In conclusion, this practical was an enriching one as it gave me a better view on the job of a chemical engineer."

However, despite being better received, the persistent thread that appears among students is that while they recognized the importance of sustainable development, they nonetheless felt that there is currently a limited role that they can play as students. The following responses are somewhat typical:

"We do not think there is much we can do at this point, as we do not have enough knowledge to make a difference."

"At this age is quite difficult, but maybe at an older age."

We believe one of the main reasons for this perception is the relatively high standard of living enjoyed by the population, and many students had thus grown up in such an environment of relative abundance that without experiencing some of life's challenges first-hand, the notion of sustainability is difficult for them to grasp indeed.

MOVING AHEAD

In attempting to address the challenge of perceived lack of immediacy in the Singapore context, we believe that a further movement towards a transformational "re-build" strategy, as identified earlier in Table 1 (i.e. education as sustainability), is now essential to enhance our students' sustainability literacy. This approach calls for us to strengthen our established partnership with local industries, in which sustainable development is a very visible proposition. For example, in Singapore we intend to widen our collaborations with local farmers to assist them in sustainable practices, including waste conversion to biogas and fertiliser, as well as more innovative farming methods. These farms are few of the surviving ones in land-scarce Singapore located in a more remote north-east region of the island. These projects focus on using low-cost, low-technology solutions that are appropriate for the local farmers.

In the past, such partnership took the form of several projects for our final year students, numbering about 6-9. Such efforts had shown positive results whereby students are able to apply what they learnt in chemical engineering to improve resource utilization in the farm. Feedback from the students also showed that they found meaning in the work that they did, despite having to work under the hot sun, smell of manure, and often subjected to the endless harassments of mosquitoes as well.

We now intend to scale-up our collaboration by effectively setting up a classroom in the farm itself, so that students can spend at least one day a-week learning out of the classroom. To achieve this, we need to make changes to our course structure to accommodate such an arrangement. Such a learning environment will expose students to a diversity of disciplinary and stakeholder perspectives – as aptly summarized by van Dam-Mieras [40]: "Most learning environments in traditional formal education do not optimally support that type of learning."

To this end, we are continuing our efforts to integrate sustainable development into other core chemical engineering modules, as shown in Table 2, using the approach outlined in this paper. We would like our students to understand how basic principles besides chemical reaction engineering (for example, heat transfer and equipment, separation processes) can contribute to sustainable development. In this way, we hoped to enhance their confidence in their own ability, and dispel the notion that "they are too young to contribute to sustainable development". Such collaborations with the local farms can also provide the desired local context that can better build empathy among students.

This new way of learning will also strengthen the third pillars of sustainable development "triple bottom line", namely that of socio-centric concerns. Through various projects, students can gain a better understanding of the significance of these three overlapping circles and develop a greater appreciation that they can indeed make a difference. At this time of writing, we are in the process of seeking funding support to set up this facility.

CONCLUSION

This paper documents the approaches currently adopted by the Diploma in Chemical Engineering to integrate sustainable development into its curriculum. Indeed, we have experienced the inherent challenges in Allen and Shonnard's [41] framing that "… 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". However, we feel that collaborative and experiential projects directed at real community concerns in context, as outlined in the previous section, offer our best educational efforts in impacting students thinking and feelings of human relevance towards this critical global need.

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