CONTEXTUALIZE TEACHING OF ETHICS IN CHEMICAL 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. Since adoption, specific CDIO skills have been successfully integrated 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 presents the approach taken by DCHE to integrate engineering ethics (EE) into its curriculum. Firstly, through a comparison of Massachusetts Institute of Technology (MIT) and Singapore Polytechnic's customized CDIO Syllabus, key concepts relating to engineering ethics are derived and applied to the context of chemical engineering.

Secondly, based on a literature review on teaching EE; key perspectives (e.g. "micro" or "macro" focus), approaches (e.g. case studies, codes of ethics), and issues relating to proficiency levels and who is best positioned to teach such content, are explored.

Thirdly, we share our approach that balances both micro and macro focus to integrating ethics into the curriculum. We present integration examples in the 3-year curriculum, emphasizing a case-based learning approach using the famous "Incident at Morales" video. The pedagogic methods encourage students' critical thinking to build understanding of social and organizational aspects of engineering contexts, especially the different underlying valuations that, consciously or otherwise, often shape engineering decisions. We also summarize results from student surveys on their learning experiences, identifying issues and challenges faced, as well as key pedagogic insights.

Finally, we offer some recommendations for future work to further enhance understanding and practice in this very pedagogically challenging curriculum area.

KEYWORDS

Engineering ethics, code of ethics, case study, chemical engineering, CDIO skills

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) in Singapore Polytechnic (SP) 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) have been integrated into the curriculum. This paper shares the efforts by the DCHE Course Management Team (CMT) to integrate engineering ethics into various core modules in the diploma's 3-year curriculum.

In discerning what ethics means to chemical engineering, we asked the same question posed by Crawley et al [1]:
- 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?

As in past curriculum development activity, we adapted the original MIT CDIO Syllabus and developed SP's own customized CDIO syllabus for ethics. We then surveyed the vast literature for best practices on the teaching (and learning) of ethics and used this to guide our own approach for negotiating this challenging content area.

BRIEF REVIEW ON TEACHING OF ENGINEERING ETHICS

A detailed account on the evolution of the education of engineering ethics was given by Mitcham [2]. Bowden and Smythe [3] identified four principal objectives of teaching ethics: (1) Building ethical sensitivity and moral cognition; (2) Providing a widened applied teaching content that covers all ethical practices; (3) Adopting teaching methods that maximise learning impact in relation to ethical knowledge and behaviour; and (4) Developing negotiating and persuasive capabilities (oral and written skills) for use in assessing and advocating an ethical position.

Abate [4] maintained that there is justification to teach only insofar as we are able to clearly identify the most desirable and efficacious pedagogical approach to the subject area. Pfatteicher [5] thus framed the current engineering ethics "dilemma" as "to find a way to provide meaningful ethics instruction to all engineering students without overburdening faculty, without increasing graduation requirements, and without removing essential technical material from the curriculum." She noted that "few engineering faculty object, in principle …… but many struggle with the practical question of just how to instil this understanding of ethics in their graduates."

Crediting the ethicist John Ladd, Herkert [6] posits that engineering ethics can be divided into "micro ethics" or "macro ethics" depending on whether the focus in on relationships between individual engineers and their clients, colleagues or employers, i.e. issues which for the most part are internal to the profession; or on the collective social responsibility (external) of the profession. There had been widespread criticisms on the predominantly "micro' focus of ethics education, which centred on individual engineer's decision-making, ignoring the wider aspect of which engineering is practiced. Bucciarelli [7] for example objected to ethics that are taught through the individualistic "object world" of the engineering profession where the broader context of social, organizational and political complexities of engineering practice is ignored. Most efforts at teaching ethics now include a "macro" focus. A focus on macro issues does not mean that micro issues disappear but rather highlights the need to widen the analysis to look at how the broader environment enables or constrains the capacity of engineers [8].

The pedagogical framework of engineering ethics education has evolved primarily toward utilization of case studies (see for example [9], [10]) and codes of ethics (see for example [11], [12]), and in some instances supplemented by an introduction to moral theory [13].

The integrated approach appears to be the favoured method. The remark by Harris et al [10] is most appealing in this regard; "Engineering ethics is part of thinking like an engineer. Teaching engineering ethics is part of teaching engineering." Through integration into core engineering modules, the teaching can bring home the point of how integral engineering ethics is to engineering practice. Flynn and Barry [14] went further to suggest that "All core modules should have some ethical component, rather than the provision of a stand-alone ethical module which is semi-detached from other modules", warning that "the stand-alone approach can lead to the danger of a 'tick box' approach, feeding into students (and perhaps staff) perception that ethics is not a core aspect of the engineering curriculum but an 'externally' imposed requirement, e.g. accrediting professional body.

This approach also puts to rest the question of who is to teach ethics to engineering students. Bowden [15] argued that "only discipline-based teachers will understand many of the technical aspects of the ethical issues that are identified." Supporting, Colby and Sullivan [16] highlighted the risk in relying on general philosophy courses (especially taught outside of engineering school) as students' only systematic exposure to ethics may result in students not knowing how to connect what they learn to their own work. We couldn't agree more!

Lastly, on the level of proficiency that we must train our students, we look to the view as articulated by the Royal Academy of Engineering [17], shown in Table 1.

Table 1. Learning Outcomes of Students Learning Engineering Ethics

| Level	Focus	Students should be able to:
1	Awareness of issues, obligations and responsibilities; sensitizing students to ethical issues	1. Give examples of ethical issues related to engineering 2. Recognize ethical responsibilities of engineers 3. Describe in outline an ethical framework for engineering
2	Resolving practical problems; enabling students to identify ethical issues and to examine and weigh up opposing arguments	1. Identify ethical issues related to an engineering situation 2. Suggest ways to deal with ethical issues in engineering 3. Illustrate the ethical dimension of practical engineering
3	Reflection and critique of ethical issues; consolidation of ethics skills and practice; specialist study	1. Undertake an ethical audit 2. Discuss ethical dilemmas in engineering 3. Justify an ethical stance
4	Further reflection and critique of ethical issues; specialist study	1. Articulate ethical problems in engineering 2. Reach an ethically justified or morally reasoned practical solution to an ethical problem with an appropriate plan of action 3. Propose policy relating to ethical questions in engineering

DIPLOMA IN CHEMICAL ENGINEERING: WORK DONE

At the diploma level, we pegged the learning outcomes at RAE's Level 1 and Level 2. We used a hybrid of approaches to integrate engineering ethics into our curriculum, using a potpourri of case studies, code of ethics, as well as scenario-based learning which is now a familiar component in all our CDIO-enabled laboratory activities. We used the same model as that for integrating various CDIO skills into the curriculum in past efforts. Table 2 shows the core chemical engineering modules where ethics had been integrated.

Table 2. Core Modules in Chemical Engineering with Ethics Integrated

Year	Module Name	Component	Type of Ethics	Topic
1	Introduction to Chemical Engineering	Tutorial – group discussion	Macro	Food resources for biofuels, Bhopal Gas Tragedy
	Pharmaceutical Microbiology	Tutorial – case study	Micro	Non-conformance of infant-toddler vaccine
2	Environmental Engineering	Tutorial – group discussion on case study	Micro and Macro	Leakage of chemical waste in off-site location
	Plant Safety and Loss Prevention	Tutorial – group discussion through 2 case studies	Macro	Duty of Care; Piper Alpha accident
	Bioanalytics	Laboratory Activity	Micro	Biohazardous waste
3	Separation Processes	Laboratory Activity	Micro	Vendor is ex-classmate
	Bioprocess Engineering Principles	Laboratory Activity	Micro	Revealing proprietary information
	Professional & Personal Development in ChE	Tutorial – Group Assignment	Micro and Macro	"Incident at Morales" video
	Quality Management & Statistics	Tutorial – Group discussion	Micro	Tip off and surprise inspection visit
	Thermodynamics	Reflection Journal	Macro	Nuclear energy, weaponry

The rest of the paper largely centres on the teaching of ethics in two core modules: one in Year 1 and another in Year 3. In Year 1, which uses the Bhopal Gas Tragedy as *the* case study, our emphasis is mainly focused on encouraging student awareness of ethical issues in engineering decision making.

Greater emphasis is placed on work done in Year 3, which is based on the "Incident at Morales" video produced by The U.S. National Institute for Engineering Ethics (NIEE). The case involves a variety of ethical issues faced by a company that wants to quickly build a plant in order to develop a new chemical product to gain a competitive edge over the competition. Potential technical issues and ethical issues arise from choice of designs, including choice of plant site, valves, piping, chemicals and automated control system. The process also involves high temperatures and pressures and requires the use of chemicals that need special handling. Technical, environment, financial and safety problems can arise that involve ethical issues. The case enables students to identify ethical issues and to examine and weigh up opposing argument with reference to Code of Ethics. The video is 36 minutes long and comprises three segments. After each segment, students are asked to identify and list down all the possible ethical issues on post-it notes. At the end of the video session, the lecturer facilitates a discussion and categorizes the issues together with students using affinity diagrams, as shown in Figure 2.
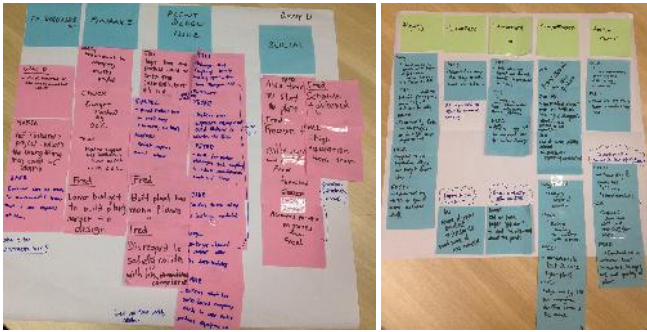
(a) Categorizing of issues by student groups
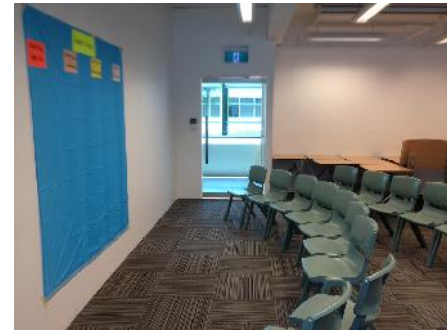
(b) Classroom set-up for facilitation
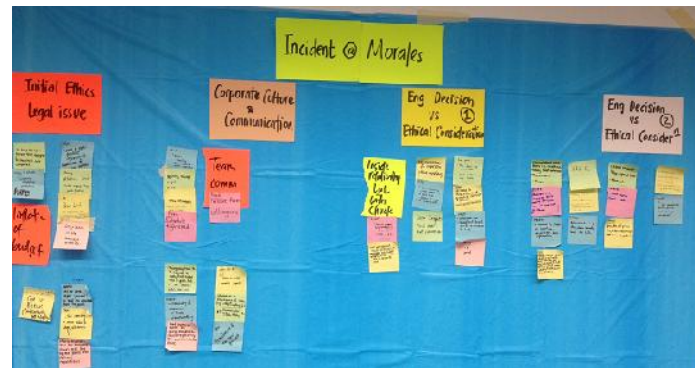
(c) Facilitation of possible ethical issues from video "Incident at Morales" using affinity diagram.

Figure 2. Facilitation of In-Class Discussion Using Affinity Diagram

Each student group is tasked to analyse the ethical issues with reference to "Code of Ethics of Engineers" and concepts of "Responsible Care". Students are also asked to suggest ways to deal with ethical issues if they were in charge. The analysis of ethical issues could be presented in different ways, such as PowerPoint presentation, poster presentation, role-playing, skit performance, animated video, puppet show or other creative ways. After the presentation of each group, lecturers will then provide their critiques on the analysis. The session concludes with a summary and illustration of ethical dimensions relating to practical engineering and how these may impact on society and the environment.

Students Learning Experience

We conducted a questionnaire survey on students' learning experience of engineering ethics for Year 1 and Year 3 students respectively. We used a Likert 5-point scale whereby students are required to rate from a score of 1 ("Strongly Disagree") to 5 ("Strongly Agree"). A total of 80 Year 1 students and 94 Year 3 students responded to the questionnaire survey.

We asked Year 1 students on their awareness of possible ethical issues and impact of engineering on the society and environment through the "The Bhopal Gas Tragedy" case study, and if they agree that it is important to study engineering ethics in the context of an engineering module. From the survey result, more than 90% of the students agreed that the case study has increased their awareness of possible ethical issues and 90% of the students agree that the case study has exposed them to the application of Code of Ethics, as shown in Figure 3 and 4 below. 88% of the students also agreed that a case study approach was useful in learning ethics as compared to theoretical delivery in lecture.
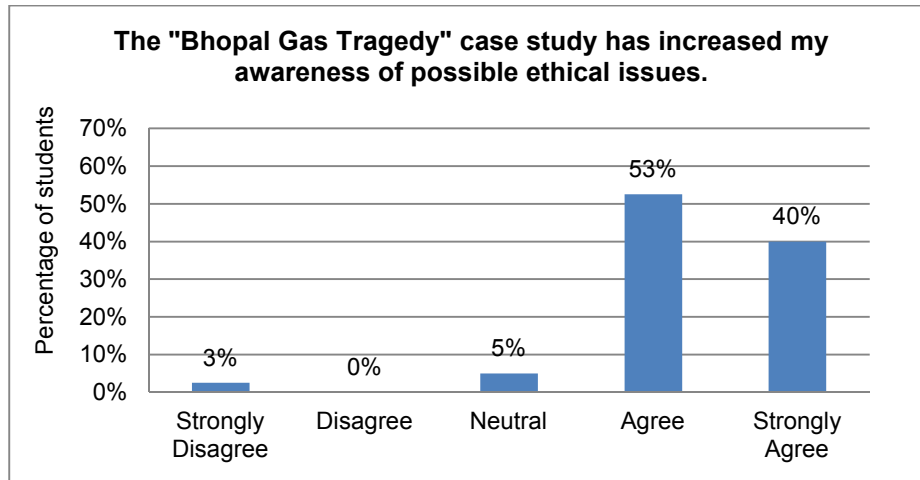
The "Bhopal Gas Tragedy" case study has increased my awareness of possible ethical issues.

Figure 3. Year 1 student responses on awareness of the possible ethical issues

The "The Bhopal Gas Tragedy" case study has exposed me to the application of Code of Ethics.
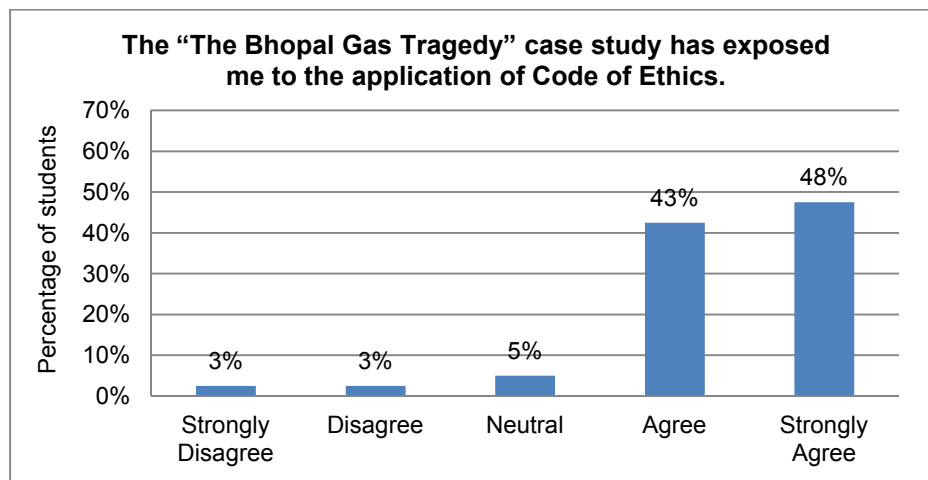
Figure 4. Year 1 student responses regarding their exposure to the application of Code of Ethics

The survey results from Year 3 students showed that students' learning experience on engineering ethics through "Incident at Morales" case study was positive. 89% of students responded that the case study has enhanced their understanding of how to apply Code of Ethics to resolve ethical dilemmas, as shown in Figure 5. More than 80% of students also agreed that the case study has improved their ability to make sound judgements according to the rules of professional conduct when faced with ethical dilemmas.

Comparing to the survey results with Year 1 students, we could summarize that there is an enhancement of students learning from awareness to application of Code of Ethics to deal with ethical issues. The results showed that most students agreed that the case studies has widened their understanding and provided them with greater insight of possible engineering ethical issues and the application of Code of Ethics to resolve ethical dilemmas. Some even suggested that more case studies could be used to illustrate the impact of ethical considerations in making engineering decisions and how the decisions could impact on the society, safety and environment. It was also suggested that learning on engineering ethics with moral values of right and wrong behaviour should be covered more in-depth.

The "Incident at Morales" case study has enhanced my understanding of how to apply Code of Ethics to resolve ethical dilemmas.
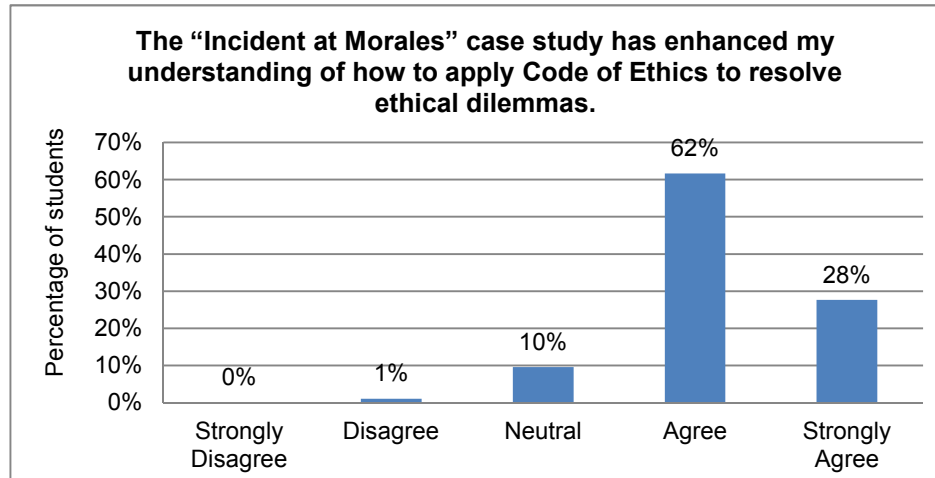

Figure 5. Year 3 students' response on application of Code of Ethics to resolve ethical dilemmas

The above findings are consistent with an independent survey administered by the Department of Educational Development (EDU) on the effectiveness of our CDIO implementation. This survey (again using the same 5-point Likert scale), which targets Year 1, Year 2 and Year 3 students; yielded the following results shown in Table 3.

Table 3. Student responses to usefulness of learning engineering ethics

Question: The modules have helped me to	Year 1 (no. of respondents = 66)	Year 2 (no. of respondents = 27)	Year 3 (no. of respondents = 38)
	Mean	Mean	Mean
Make sound judgements according to the rules of professional conduct.	3.407	3.407	3.763
Act in a manner consistent with the expectation of the society.	3.515	3.481	3.658

Overall, based on the mean score, the rating shows an increasing trend indicating that through the course of study, students have progressively strengthened their grasp of the concepts and achieved greater understanding of ethical considerations in acting responsibly as engineers.

ISSUES AND CHALLENGES

The lecturers encountered several issues and challenges in the teaching of engineering ethics. The most prominent concerns students' initial reluctance to engage in what is perceived as "soft" (non-numerical) subject matter, where answers are rarely clear-cut. The problem is further compounded by an absence of expertise among academic staff, or reluctance of engineering academics to specialize in this subject domain. The pedagogic approach of case-based learning for the teaching of engineering ethics is another challenge for academic staff, as it requires good facilitation skills, which are especially important when dealing with value-laden issues and managing critiques to student analysis on ethical issues. Conversely, those routinely specializing in the study of ethics rarely have the technical background to present topics in a format that may

appear relevant to stimulate the interest of engineering students. Some staff also believed their professional experience is inadequate for the task.

Another challenge for the effective learning of engineering ethics is the need for small group discussion, which creates problems with large students cohorts. The argument for small classes in this learning context is that they encourage more interactions, where students learn from each other and from the lecturer and come to understand their own and others ethical viewpoints more clearly. In our experience, for interactive presentations and discussions to work well, class sizes should not exceed about 30 people.

Assessment also proved to be a challenging area that requires further research and application. Shuman et al [18] cautioned that to date, methods to assess students' ability to resolve ethical dilemmas remain largely undeveloped. At present, we are focusing our assessment on student's ability to: (1) Identify and analyze ethical issues in relation to different evaluative frames of reference (e.g. engineering "Code of Ethics", personal value systems, universal values, etc.); and (2) Apply ethical reasoning to both micro and macro engineering situations and issues. This is done through a range of methods, including critique and questioning, using both faculty and peer assessment.

Finally, although we feel that we have been technically successful in integrating engineering ethics into our curriculum, there is uncertainty as to the extent to which our students will behave as ethical professionals in the real world of practice. This is aptly noted by Bowden and Smythe [3] that "although a course may bring about a desirable increase in intellectual awareness of the rights and wrongs of moral issues, such an increase does not necessarily ensure that people with strengthened moral reasoning will then act ethically." The relationship between moral reasoning and moral behaviour is complex and not well understood. Additional studies are needed regarding the relationship of moral reasoning skills and behavioural manifestations flowing from those skills.

MOVING AHEAD

In attempting to address the challenge of students' reluctance to engage in what is perceived as "soft" (non-numerical) subject matters, more relevant and real-life scenarios and cases will be used to provide impact and context to the student learning experience in this challenging curriculum area. To enhance the learning experience further we will invite industry personnel to share their experiences with students in dealing with ethical dilemmas in real engineering contexts. From a teaching perspective we can only provide students with experiences and insights into ethical issues and encourage their thinking in certain ways, making explicit the range of economic, social and psychological consequences of certain actions. Ultimately, they will make their choices if and when such dilemmas arise. We can only hope that we have given them a useful resource to make better choices. Also, there is a need to construct a more valid and efficient assessment framework, for example, analytic scoring rubrics focusing on key constructs underpinning ethical reasoning. Making our assessment criteria more precise and explicit will make the assessment process more rigorous and reliable.

Although we are comfortable in teaching engineering ethics to students, we do face a challenge when it comes to providing critiques of student analysis on ethical issues. For example, some students argue that there are no clear-cut right or wrong answers as they may have different moral values, and what if they have to face the risk of losing their job if they choose to make engineering decision with reference to Code of Ethics which disobeys the instruction from their

employer. Dealing with ethical dilemmas is not easy and the role of the facilitator in this situation is to help students unpack the situation, identify possible consequences of different actions and encourage sustained good thinking. Telling students what is 'technically' ethically correct is not the only possible response. It is also likely to have limited impact as the only response. As such, staff involved in such facilitation activities may need further professional development in order to manage these challenges in the best way possible.

CONCLUSION

This paper represents our initial efforts at integrating engineering ethics into the curriculum. As documented, we feel that the real progress has been made in terms of developing a more effective and integrated approach in contextualizing of teaching engineering ethics in chemical engineering curriculum. Difficult pedagogic challenges in the teaching of ethics remain, whether in the context of engineering or elsewhere. We hope to continue in the present vein as best we can – it is too important a curriculum area to negate.

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BIOGRAPHICAL INFORMATION

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