ENHANCING ONE'S TEACHING AND LEARNING APPROACHES BY BENCHMARKING AGAINST CDIO EDUCATION FRAMEWORK

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ABSTRACT

This paper demonstrates how one can enhance his or her own teaching and learning (T&L) approaches by benchmarking against the Conceive-Design-Implement-Operate (CDIO) education framework. Firstly, the paper will enumerate T&L challenges that are faced by polytechnic educators in Singapore today. Thereafter, the paper will argue that there is a need to go beyond traditional discipline-based and performance-based T&L approaches (Toohey, 1999) as they are no longer effective in surmounting and overcoming today's T&L challenges. Consequently, the paper will recommend educators to adopt experiential and socially critical T&L approaches instead (Toohey, 1999). Such T&L approaches have their bases in cognitive constructivism (Piaget, 1968) and social constructivism (Smagorinsky, 2013), and have also been found by Biggs (1987) and Ramsden (1992) to promote deep-learning in students. Most significantly, in the context of this paper, such T&L approaches are fully congruent with the CDIO standards in the CDIO education framework. As such, the remaining of the paper will provide illustrations on how the experiential and socially critical T&L approaches can be benchmarked against CDIO standards 2, 3, 4, 5, 7, 8 and 11. Finally, the paper will conclude with anecdotal evidence to support the adoption of such CDIO-benchmarked T&L approaches as a means to enhance key aspects of one's teaching practice.

KEYWORDS

Teaching and Learning Approaches, Benchmarking, Standards 2, 3, 4, 5, 7, 8 and 11.

TEACHING AND LEARNING CHALLENGES

The myriad of teaching and learning (T&L) challenges that are faced by polytechnic educators in Singapore today stem from policies, directions and changes that have occurred at the macro-level (i.e. organisational, national and global levels) and micro-level (i.e. module and diploma levels).

To begin with, at the macro-level, polytechnic education in Singapore started back in 1954 with the establishment of Singapore Polytechnic (SP) as its first polytechnic, and primary aim of the polytechnic education was simply to "provide training for skilled personnel to spearhead and man wide-ranging industries and businesses in Singapore" (Singapore Polytechnic, 2013).

However in Singapore today, majority of the polytechnic students look to polytechnic education as a stepping stone to universities rather than as a gateway to industries. Hence, it is not difficult to imagine the T&L challenges that are faced by polytechnic educators in designing and delivering a curriculum that will meet the starkly different needs of both the academia and the industry.

To complicate matters further, at another macro-level, changing industry landscape in Singapore and beyond has brought forth a range of brand new skills such as trans-disciplinary knowledge, cross-cultural competency and design mindset that students should possess in order to be a competent 21st century worker (Institute for the Future, 2011).

Additionally, with the advent of technology (in particular, mobile technology), profiles of the polytechnic students have evolved drastically over the years. The current students are commonly known as the Millennials and in five years' time, the students will be known as the Digital Natives (Prensky, 2001). According to a global survey on "The Truth about Youth", these two profiles of students "would rather give up their sense of smell than (mobile) technology" (McCann Worldgroup, 2011).

Therefore, just like before, it is not difficult to imagine the T&L challenges that are faced by polytechnic educators in designing and delivering a curriculum that will be able to meet the needs of both the changing industry landscape, as well as the changing student profiles.

Next, at the micro-level, with particular reference to Diploma in Chemical Engineering (DCHE), lack of prior disciplinary knowledge in first-year DCHE students poses one major T&L challenge. A handful of the DCHE students have a common fallacy in thinking that they have enrolled into a chemistry course. As such, some of them gradually become disconnected and disinterested in DCHE, which often leads to academic and disciplinary issues. On the other hand, students who remain motivated and passionate about DCHE also struggle to perform as they experience a steep learning curve.

Lastly, at another micro-level, diversity of DCHE as a discipline presents yet another T&L challenge. Chemical engineering, a discipline that branched off from applied industrial chemistry and traditional mechanical engineering in the early 20th century, has grown and is continuing to grow in a wide variety of fields ranging from petrochemical to pharmaceutical to water to nanotechnology and many more. Thus, DCHE educators struggle to incorporate the ever-expanding disciplinary knowledge into the already-packed DCHE curriculum, while DCHE students struggle to connect-the-dots between the traditional and the new disciplinary knowledge.

Henceforth, hitherto, there is no dubiety that polytechnic educators in Singapore face a plethora of T&L challenges at both the macro-level and the micro-level.

LIMITATIONS OF TRADITIONAL TEACHING AND LEARNING APPROACHES

In view of the multitude of T&L challenges that are faced by polytechnic educators in Singapore today, traditional T&L approaches such as discipline-based and performance-based T&L approaches (Toohey, 1999) are no longer effective.

With the ease of accessing knowledge by means of mobile technology, students today have less reliance on polytechnic educators to didactically transmit the knowledge to them in class.

Polytechnic educators who adopt discipline-based T&L approach that involves curriculum design and delivery in a didactic fashion will thus find themselves losing the attention of their students after 10 to 20 minutes of their lessons. Moreover, it is also near impossible for polytechnic educators to didactically transmit all of the ever-expanding disciplinary knowledge in an already-packed curriculum.

Similarly, polytechnic educators who adopt performance-based T&L approach that involves curriculum design and delivery whereby students are subjected to extensive drilling practices so as to hopefully ensure the students can perform during examinations will find that their students more often than not will "auto-delete" the knowledge learnt after examinations. Additionally, these polytechnic educators will also experience a common phenomenon whereby their students may have performed well in a particular module but fail to be able to apply the knowledge learnt in that module in another context.

As such, there is little ambiguity that traditional discipline-based and performance-based T&L approaches are highly limited in today's very challenging education climate.

EXPERIENTIAL AND SOCIALLY CRITICAL TEACHING AND LEARNING APPROACHES

Hitherto, it is palpable that with the plethora of knotty T&L challenges and limitations of traditional discipline-based and performance-based T&L approaches, polytechnic educators must now look to employing more appropriate T&L approaches such as experiential and socially critical T&L approaches (Toohey, 1999).

Experiential and socially critical T&L approaches have their bases in cognitive constructivism (Piaget, 1968) and social constructivism (Smagorinsky, 2013). That is to say, unlike the traditional discipline-based and performance-based T&L approaches, under the experiential and socially critical T&L approaches, students will take on a self-directed role in their knowledge construction, while educators will only serve to assist and facilitate the students' learning plans.

Table 1: Surface-Learning versus Deep-Learning

Surface-Learning	Deep-Learning
Learning is acquisition of knowledge that is simply memorised and regurgitated when needed; with facts and concepts unreflectively associated.	Learning is sense-making that involves relating prior knowledge to new knowledge, connecting knowledge from different modules, as well as constructing and reconstructing knowledge based on real world experiences.
Tasks related to learning are taken as external impositions.	Tasks related to learning are structured and organised into a coherent whole.
Students' motivation to learning is externally driven by demands of assessment.	Students' motivation to learning is internally or intrinsically driven by feeling of "gratifying challenge".

Furthermore, based on empirical research done by Marton and Saljo (1976), Entwistle (1981), Biggs (1987) and Ramsden (1992), it has also been found (as summarised in Table 1) that experiential and socially critical T&L approaches will promote deep-learning in students, while traditional discipline-based and performance-based T&L approaches will only promote surface-learning in students.

Therefore, it is argued, in this context, that experiential and socially critical T&L approaches are the more appropriate T&L approaches that polytechnic educators should employ in today's very challenging education climate.

BENCHMARKING EXPERIENTIAL AND SOCIALLY CRITICAL TEACHING AND LEARNING APPROACHES AGAINST CDIO EDUCATION FRAMEWORK

Having seen the relevance of experiential and socially critical T&L approaches for polytechnic educators in today's education climate, it is important to note that in the context of this paper, such T&L approaches can be benchmarked against the CDIO education framework. In other words, experiential and socially critical T&L approaches are fully congruent with the CDIO standards in the CDIO education framework, in particular with CDIO standards 2, 3, 4, 5, 7, 8 and 11 (CDIO, 2013).

Table 2: The 12 CDIO Standards in the CDIO Education Framework

	CDIO Standards
1	CDIO as context
2	CDIO syllabus outcomes
3	Integrated curriculum
4	Introduction to engineering
5	Design-implement experiences
6	CDIO workspaces
7	Integrated learning experiences
8	Active learning
9	Enhancement of faculty CDIO skills
10	Enhancement of faculty teaching skills
11	CDIO skills assessment
12	CDIO programme evaluation

Benchmarking Against CDIO Standard 2

Thus, beginning with CDIO standard 2, it is stated that besides technical disciplinary knowledge, personal, interpersonal, product and system-building skills must also be included as key learning outcomes in a CDIO programme. Details of the various required learning outcomes under CDIO standard 2 are found in the CDIO syllabus V2.0 (Crawley, Malmqvist, Lucas and Brodeur, 2011).

With particular reference to DCHE, in order to satisfy CDIO standard 2, DCHE Course Management Team (CMT) performed a comprehensive mapping of all the DCHE modules to the various required learning outcomes in CDIO syllabus V2.0. After which, the mapping resulted in rewriting of the DCHE module syllabi and redesigning of T&L activities in the DCHE modules.

An illustration of a rewritten DCHE module syllabus for module *Introduction to Chemical Product Design* (*ICPD*) is shown in Table 3, while the mapping of *ICPD* learning outcomes to CDIO syllabus V2.0 is shown in Table 4.

At this juncture, it is to be noted that the design and delivery of *ICPD* is based on experiential and socially critical T&L approaches. Greater delineations of how experiential and socially critical T&L approaches have been adopted in *ICPD* will be presented in the subsequent sections of the paper.

Therefore, based on Table 4 thus far, it is evident that *ICPD* learning outcomes are aligned to CDIO syllabus V2.0, which in turn implies that experiential and socially critical T&L approaches that have been adopted in *ICPD* are benchmarked against CDIO standard 2.

Table 3: Rewritten Module Syllabus of *ICPD*

	Learning Outcomes
1.1	Describe categories of chemical products.
1.2	Describe different phases of chemical product design.
1.3	Explain importance of chemical product design.
1.4	Describe different phases of design thinking.
1.5	Explain importance of design thinking in chemical product design.
2.1	Illustrate designs of chemical products that are used in our daily lives, in the industries or for the world's underprivileged populations.
2.2	Explain global nature of chemical product design.
2.3	Explain importance of sustainability in chemical product design.
2.4	Explain chemical engineering principles and their applications in chemical products.
2.5	Apply chemical engineering sciences to discover how chemical engineering principles are employed in design and manufacture of chemical products.
3.1	Describe different types of design team.
3.2	Explain importance of teamwork and communication in a design team.
3.3	Apply teamwork and communication in various activities such as an introductory-level Design-Implement Experience (DIE) project.
4.1	Conduct ethnographic observation and interviews of target customers.
4.2	Analyse collected ethnographic observation and interviews data.
4.3	Infer and interpret customer needs from the analyses of the ethnographic observation and interviews data.
5.1	Translate customer needs into preliminary product design specifications.
5.2	Explain performance metrics for the preliminary product design specifications.
5.3	Analyse competitors' products and refine preliminary product design specifications.
6.1	Explain differences between intellectual property and intellectual property rights.
6.2	Describe differences between patent, copyright, trade secret and trade mark.
7.1	Apply a range of ideation techniques to fulfil the preliminary product design specifications.
7.2	Apply a range of ideas selection methods.
7.3	Describe trade-offs in chemical product developments.
8.1	Convert selected ideas into 2D sketches.
8.2	Create 3D "quick and dirty prototypes" based on the 2D sketches.

Table 4: Mapping of *ICPD* Learning Outcomes to CDIO Syllabus V2.0

	CDIO Learning Outcomes under CDIO Syllabus V2.0																
ICPD Learning Outcomes	1.1	1.2	1.3	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
1.1		■															
1.2		■															
1.3		■															
1.4		■															
1.5		■															
2.1								■				■	■				
2.2								■				■	■				
2.3								■				■	■				
2.4		■															
2.5	■			■	■		■		■	■							
3.1									■								
3.2									■	■							
3.3				■	■		■	■	■	■							
4.1					■												
4.2					■		■							■			
4.3					■		■							■			
5.1				■			■								■		
5.2		■					■								■		
5.3				■			■								■		
6.1												■	■				
6.2												■	■				
7.1							■								■		
7.2							■								■		
7.3		■					■								■		
8.1							■									■	
8.2																■	

Benchmarking Against CDIO Standard 3

Next, looking at CDIO standard 3, it states that it is necessary to design a curriculum whereby various CDIO learning outcomes are integrated across mutually supporting disciplinary modules.

With reference to *ICPD* in DCHE again, learning outcomes of *ICPD* are integrated with modules such as *Analytical and Physical Chemistry* (*APCHEM*), *Inorganic and Organic Chemistry* (*IOCHEM*), *Teamwork and Communication Toolbox* (*TCT*) and *Introduction to Chemical Engineering* (*ICHE*). The integration of *ICPD* learning outcomes with the above-mentioned modules is shown in Table 5.

Table 5: Integration of *ICPD* Learning Outcomes with Other Modules

ICPD Learning Outcomes		Module(s) that is/ are Integrated with the *ICPD* Learning Outcomes	CDIO Learning Outcome(s) that is/ are thus Integrated	
2.4:	Explain chemical engineering principles and their applications in chemical products.	*ICHE*	1.2:	Core fundamental knowledge of engineering
2.5:	Apply chemical engineering sciences to discover how chemical engineering principles are employed in design and manufacture of chemical products.	*APCHEM* *IOCHEM*	1.1:	Knowledge of underlying mathematics and sciences
		TCT	3.1: 3.2:	Teamwork Communication
		ICHE	1.2:	Core fundamental knowledge of engineering
3.3:	Apply teamwork and communication in various activities such as an introductory-level Design-Implement Experience (DIE) project.	*TCT*	3.1: 3.2:	Teamwork Communication

Hence, based on Table 5, it can be inferred and interpreted that the experiential and socially critical T&L approaches that have been adopted in the design and delivery of *ICPD* are benchmarked against CDIO standard 3.

Benchmarking Against CDIO Standard 4

Next, referring to CDIO standard 4, it states that there must be an introductory module that can provide students with opportunity to engage in engineering practice, as well as introduce students to essential personal and interpersonal skills.

In the context of DCHE again, engineering practice under the CDIO principle comprises four stages, namely Conceive, Design, Implement and Operate. The Conceive stage involves defining customer needs by considering STEEP (i.e. Social, Technological, Environmental, Economical and Political) factors. The Design stage focuses on creating designs in the form of plans, drawings or algorithms. The Implement stage refers to transforming the designs into products. The Operate stage implies using the implemented products to deliver their intended values.

Henceforth, based on the *ICPD* learning outcomes in Table 3, it is clear that DCHE students taking *ICPD* are engaged in the Conceive – Design – Implement – Operate stages of chemical engineering practice. Additionally, it is also clear that *ICPD* introduces students to essential personal and interpersonal skills.

In other words, it can also be inferred and interpreted that the experiential and socially critical T&L approaches that have been adopted in the design and delivery of *ICPD* are benchmarked against CDIO standard 4.

Benchmarking Against CDIO Standard 5

Following which, for CDIO standard 5, it states that a CDIO programme must consist of two or more Design – Implement (DI) experiences.

As an illustration on the types of DI experiences that DCHE has, there is a T&L activity in *ICPD*, which is known as Water Filter Challenge that can be considered as a DI experience. Details of the Water Filter Challenge can be found in Appendix A.

Consequently, referring to Appendix A, it is incontrovertible that experiential and socially critical T&L approaches have been employed in the design and delivery of this *ICPD* T&L activity. That is to say, it is thus indubitable that experiential and socially critical T&L approaches are benchmarked about CDIO standard 5.

Benchmarking Against CDIO Standard 7

Thereafter, for CDIO standard 7, it states that it is essential to have pedagogical approaches that can foster simultaneous learning of disciplinary knowledge with personal, interpersonal, as well as product and system building skills. It also states that the use of such pedagogical approaches will then in turn bring about an integrated learning experience for the students.

Hence, with reference to *ICPD* in DCHE again, it is equally apparent that, based on the discussions thus far, the experiential and socially critical T&L approaches that have been employed in the design and delivery of *ICPD* are benchmarked against CDIO standard 7.

Moreover, based on the characteristics of surface-learning and deep-learning as set out in Table 1, it is not difficult to realise that CDIO standard 7 also attempts to achieve deep-learning in students through its intent of integrated learning experience. In other words, this provides additional evidence that experiential and socially critical T&L approaches that have been found to promote deep-learning in students are benchmarked against CDIO standard 7.

Benchmarking Against CDIO Standard 8

As for CDIO standard 8, it states that teaching and learning must be based on active and experiential pedagogies. That is to say, there should be less emphasis on passive transmission of information and more emphasis on engaging students in manipulating, applying, analysing and evaluating ideas.

In the context of *ICPD* again, based on the discussions thus far, it is evident enough that experiential and socially critical T&L approaches that have been employed in the design and delivery of *ICPD* are benchmarked against CDIO standard 8 too.

Nonetheless, as additional evidence to support that experiential and socially critical T&L approaches are benchmarked against CDIO standard 8, two out-of-classroom T&L trips in *ICPD* that have been designed and delivered using such T&L approaches will be expounded.

The first *ICPD* out-of-classroom T&L trip takes the DCHE students to Singapore's Red Dot Museum, while the second takes them to Singapore's Gardens by the Bay. It is to be noted that in both out-of-classroom T&L trips, mobile learning devices such as iPads have been used as a form of learning and engagement tool. Pictures of the *ICPD* out-of-classroom T&L trips are shown in Figures 1 and 2.

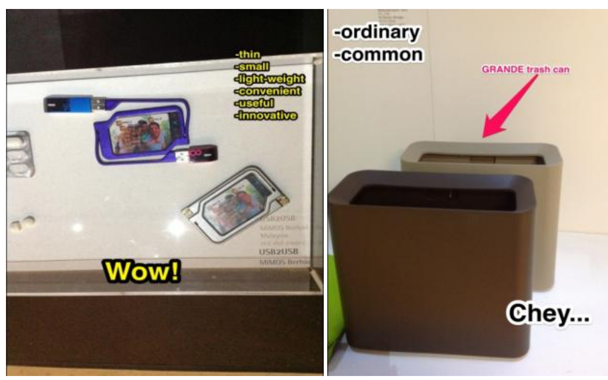

Figure 1: Students used an iPad application, *Skitch*,
to indicate Red Dot Award products that they deemed as
"Wow" and "Chey" in the context of *ICPD*.

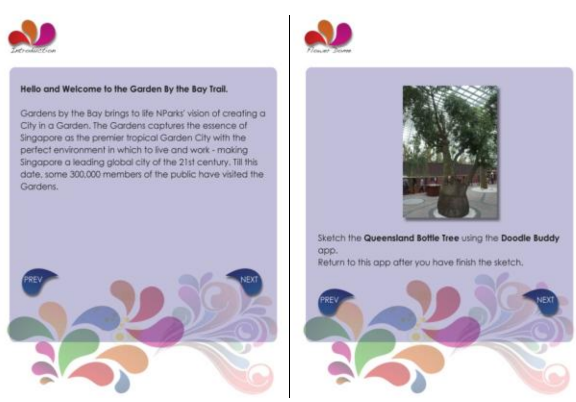

Figure 2: An iPad application has been specially designed and created
for the *ICPD* out-of-classroom T&L trip to Gardens by the Bay.
Students used the iPad application to discover sustainable
design engineering in the context of *ICPD*.

Henceforth, based on Figures 1 and 2, it can be seen that experiential and socially critical T&L approaches that have been employed in the design and delivery of the *ICPD* out-of-classroom T&L trips are benchmarked against CDIO standard 8.

Benchmarking Against CDIO Standard 11

Lastly, looking at CDIO standard 11, it states that there must be assessment of student learning as an extent to which each student achieves specified learning outcomes. In other words, the assessment of student learning must be for learning (i.e. formative in nature) and not for tests or examinations (i.e. summative in nature).

Therefore, it is has been largely the case that under the traditional discipline-based and performance-based T&L approaches, assessments of student learning are often summative in nature and "taken as an endpoint instead of a beginning or a step forward" (Birenbaum et al, 2005; Norton, 2009). On the other hand, under experiential and socially critical T&L approaches, assessments of student learning are often formative in nature.

Additionally, in the context of *ICPD* again, to aid in the formative assessments of DCHE students, assessment rubrics are used to help DCHE educators obtain clearer picture of the students' progress, as well as their strengths and weaknesses. Thereafter, the DCHE educators can make adjustments to the pace of the lessons so as to give more time to the students to actively construct their knowledge or to better facilitate the students' knowledge construction process. An illustration of an ICPD assessment rubric can be found in Appendix B.

As such, in all, it is once again ostensible that experiential and socially critical T&L approaches that have been adopted in the design and delivery of *ICPD* are benchmarked against CDIO standard 11.

CONCLUSION

Finally, based on all the analysis in this paper, a strong case has been made for a refocusing towards the adoption of experiential and socially critical T&L approaches by polytechnic educators to surmount and overcome today's T&L challenges as such T&L approaches have been demonstrated to be congruent with CDIO standards 2, 3, 4, 5, 7, 8 and 11. As a result, polytechnic educators who adopt such CDIO-benchmarked T&L approaches are more likely to benefit in terms of developing more effective aspects of their teaching practice.

Table 6: Students' Comments on the Author's Teaching

When Traditional Discipline-Based and Performance-Based T&L Approaches are Employed	When Experiential and Socially Critical T&L Approaches are Employed
"She needs to explain the subjects more clearly to the students. Her pace is too fast, and sometimes we cannot follow." "She can further improve by having more illustrations to explain certain concepts."	"A very interesting module with an interesting lecturer. Miss Claire is very good and helpful." "When in need, she provides us with ideas, as well as gives good feedback and suggestions regarding the assignments that she gave us."

As an illustration, the author of this paper has obtained significantly higher Student Feedback Score from 4.05 to 4.69 out of a 5-point scale since adopting experiential and socially critical

T&L approaches. Additionally, students' comments on the author's teaching have also markedly improved (as shown in Table 6).

While it remains a future project to ascertain more fully the learning impact, in terms of student attainment, of a more experiential and socially critical teaching approach, this paper makes the case for a more extensive adoption of experiential and socially critical T&L approaches as the main organising pedagogic framework.

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APPENDIX A – WATER FILTER CHALLENGE

1. Purpose and Context

Overall aim of the Water Filter Challenge is to promote your ability to describe, anticipate and plan for some of the realistic factors that are encountered in an engineering project.

Background

In the 1960s and 1970s, Singapore faced severe water shortages due to lack of natural water resources, flooding and pollution in our rivers. Driven by a vision of what it takes to be sustainable in water, Singapore has since then been investing in research and technology to build a robust, diversified and sustainable water supply from four different sources, better known as the Four National Taps. The Four National Taps comprise of water from local catchment areas, imported water, reclaimed water and desalinated water.

In 2008, Singapore also had an inaugural launch of the Singapore International Water Week (SIWW) as a global platform where international water community can share experiences and ideas on water solutions for the world.

Earliest recorded attempts in Sanskrit writings to find or generate pure water dated back to 2000BC. However, it was only till the early 19th century that the first municipal water treatment plant that used slow sand filter system was constructed and implemented in Scotland. Since then, other nations began to engage scientists and engineers to improve and further develop the slow sand municipal water treatment system that is still being used today.

2. Objectives

As a result of the Water Filter Challenge, you will be able to:

2.1 Recognise application of disciplinary knowledge in a design
2.2 Identify additional knowledge required to design and analyse a proposed water filter
2.3 Anticipate and plan for factors that are encountered in an engineering project
2.4 Explain ways in which critical thinking, creativity, problem-solving and experimentation are required in designing and building the proposed water filter
2.5 Describe importance of tasks division among team members that are aligned with their respective strengths and the benefit of designating a team leader
2.6 Describe need for good documentation of designs and implementation processes
2.7 Explain challenges and trade-offs to meet requirements and regulations within fixed budget and timeline
2.8 Describe benefits of conducting research and development testing without unduly delaying manufacturing process
2.9 Realise importance of designing with quality and inherent safety with the public in mind
2.10 Accept need for fair-mindedness in competitive situations

APPENDIX A – WATER FILTER CHALLENGE (CONT.)

3. Task

The Water Filter Challenge will emulate the task of engineers working in a municipal water treatment plant that uses an improved slow sand filter system, better known as rapid filter system. You and your team must build the most effective rapid water filter possible within budget and on schedule. Your final constructed rapid water filter must also be able to filter an unknown raw water feed of high turbidity and be able to produce filtered water of 80% turbidity reduction. It is also desirable that the rapid water filter has a sense of quality construction and safe to implement and operate. You and your team will have to work with realistic factors like customer requirements, pertinent regulations, analyses to support designs and engineering considerations.

4. Customer Requirements

You and your team must build the most effective rapid water filter possible within budget and on schedule (See Section 5). Only materials and tools provided (See Section 7) can be used and the final constructed rapid water filter must satisfy specific regulations (See Section 8). In the event of rapid water filters of similar effectiveness, the one with better appearance of quality construction and greater inherent safety features will be the winner.

5. Engineering Considerations

Schedule

You and your team will have approximately four hours to execute all phases of the Water Filter Challenge. Phases of the Water Filter Challenge are Conceive, Design, Implement and Operate. It is highly recommended that you and your team set an internal deadline of completing each phase.

Budget

You and your team will have a total of SGD$1,200 to spend on the Water Filter Challenge. The money can be used to purchase real estate, building and filter materials, manufacturing and laboratory testing services. It should be noted that the budget may change according to the global economic situation or financial status of your customer.

It is up to you and your team to spend as much of this budget during Conceive/ Design phases (Also known as research and development phases) to build prototypes, innovate and collect design data. However, it should be noted that no materials that are used during Conceive/ Design phases can be reused in the Implement/ Operate phases.

APPENDIX A – WATER FILTER CHALLENGE (CONT.)

Team Organisation

It is highly recommended that you and your team designate an overall project engineer, a design engineer, an implementation engineer, an operation engineer and a procurement engineer.

The overall project engineer will be responsible for coordination and project success. The design engineer will be responsible for research, development, design and design drawings. The implementation engineer will be responsible for fabrication and construction of the rapid water filter. The operation engineer will be responsible for safe and successful operation of the rapid water filter. The procurement engineer will be responsible for purchase of materials and services and finance control of the project.

6. Design Analyses

You and your team must provide the Professional Engineer results of your analyses to support the argument that your rapid water filter will be able to achieve 80% turbidity reduction in a typical raw water feed.

7. Materials Costs

All prices listed below are inclusive of 7% GST.

Real Estate	• Square plots of land of side 5cm, 10cm or 15cm • $\$2/cm^2$
Building Materials:	
Cylinder with Graduation (15cm Diameter)	• $150/pc
Cylinder with Graduation (10cm Diameter)	• $100/pc
Cylinder with Graduation (5cm Diameter)	• $50/pc
Support Filter	• $40/pc
Rubber Band	• $30/pc
Filter Materials:	
Pebble	• $14/100g
Coral	• $16/100g
Gravel	• $12/100g
Sand	• $18/100g
Manufacturing Services:	
Weighing of Filter Materials	• $1/weigh
Laboratory Testing Services:	
Turbidity Testing	• $10/test

APPENDIX A – WATER FILTER CHALLENGE (CONT.)

8. Regulations

Drawings

You and your team must submit and present drawings of the final proposed rapid water filter design to the Professional Engineer. The presentation must have clarity and depth so that the Professional Engineer is able to understand the design and implementation sequence.

It should be noted that you and your team cannot start implementing the actual rapid water filter until the Professional Engineer approves and endorses the drawings. You and your team will also have to build exactly on what is shown in the approved and endorsed drawings, and according to the proposed implementation sequence.

Effectiveness

The proposed rapid water filter must be able to achieve 80% turbidity reduction in a typical raw water feed. Description of the proposed design must be supported by data or experimental analyses conducted during the Conceive/ Design phases.

Monsoon Factor

During monsoon seasons, turbidity of the raw water feed will shoot up and the proposed rapid water filter must still be able to achieve 80% turbidity reduction. However, it should be noted due to the increasingly stringent water quality standards, the Professional Engineer may raise the turbidity reduction requirement to a higher value.

Safety and Risk Mitigation

To ensure safety of you and your team, as well as the public, all phases of the Water Filter Challenge must be conducted in the approved workspace. All materials and services must be purchased from authorised personnel who are approved by the Professional Engineer.

You and your team are also expected to perform appropriate housekeeping to maintain a neat and safe work environment at all times.

9. Assessment

The following will be used as basis for assessing the learning objectives:

9.1 Accuracy, breadth, depth and completeness of design analyses to support the argument that your proposed rapid water filter is effective
9.2 Clarity and depth of drawings and presentation that explain design and implementation sequence
9.3 Extent in which you and your team meet customer requirements
9.4 Extent of housekeeping practice that demonstrates safety consciousness and workplace consideration of you and your team
9.5 Submission of a Team Journal that communicates your achievement of the learning objectives (See Appendix D1 for the questions for Team Journal)

APPENDIX A – WATER FILTER CHALLENGE (CONT.)

Appendix D1 Questions for Team Journal

Conceive/ Design Phases

1. How did you apply your chemical engineering knowledge in the Water Filter Challenge? What other scientific and engineering knowledge are needed and applied?
2. What R&D did you conduct? To what extent was it useful? How did you decide on the budget to spend on R&D?
3. How did you apply critical thinking, creativity, problems-solving and experimentation in the Water Filter Challenge?
4. How did you interpret the customer requirements?
5. How did you account for the potential changes? Did you do a design that is robust to potential changes? What is the responsibility of engineers to anticipate changes in requirements and regulations?
6. Why is good project documentation important?

Implement/ Operate Phases

1. To what extent did you build to what is rendered in the design drawings? Did you introduce any further innovation?
2. How did you decide on budget planning and time management?
3. What did you learn about the need to implement with quality and operate with safety?
4. To what extent was being fair-minded in competitive situations considered?
5. What project engineering leadership structure did you adopt? How did you organise your team? How well did it work?
6. What did you learn from the Water Filter Challenge that can be generalised to other engineering projects?

APPENDIX B – ICPD ASSESSMENT RUBRIC

Assessment Component	Poor	Fair	Good	Very Good
Teamwork (NB: Criteria of constructive team climate = treat team members with respect; use positive tone and body expressions; express confidence in abilities of team members; provide timely and adequate assistance to team members)	- No or little contribution to team discussions (E.g. no sharing of ideas)	- Fair contribution to team discussions (E.g. occasionally offer new ideas)	- Good contribution to team discussions (E.g. frequently offer new ideas, or build upon ideas of others)	- Very good contribution to team discussions (E.g. frequently offer new ideas, or articulate merits of alternative ideas to help team move forward)
	- No or poor conflict management - No or poor support of constructive team climate - No or little contribution to team assignments (E.g. passively accept or aggressively deny alternative perspectives, do not complete assigned tasks on time, or with low quality work)	- Fair conflict management - Fair support of constructive team climate - Fair contribution to team assignments (E.g. redirect focus towards task at hand and away from conflict, complete assigned tasks on time, or with fair quality work)	- Good conflict management - Good support of constructive team climate - Good contribution to team assignments (E.g. identify and acknowledge conflict and attempt to resolve conflict, complete assigned tasks on time, or with good quality work)	- Very good conflict management - Very good support of constructive team climate - Very good contribution to team assignments (E.g. resolve conflict to strengthen overall team cohesiveness and effectiveness, complete assigned tasks on time, or with very quality work, or proactively help team members complete assigned tasks to similar level of excellence)

BIOGRAPHICAL INFORMATION

Claire Ng Huiting is the Course Manager for Diploma in Chemical Engineering in School of Chemical & Life Sciences at Singapore Polytechnic. Additionally, she is also one of the Academic Mentors in her institution. She has been actively involved in the curriculum redesign of the Diploma in Chemical Engineering by means of CDIO and Design Thinking adoption. Her current academic scholarly activities include utilisation of mobile learning devices, as well as designing of flipped classroom activities.

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