FLIPPING A CHEMICAL ENGINEERING MODULE USING AN EVIDENCE-BASED TEACHING APPROACH

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ABSTRACT

This paper shares the approach taken for the Diploma in Chemical Engineering (DCHE) to redesign a Year 3 core module entitled *Plant Safety and Loss Prevention*, using an evidence-based teaching approach delivered via a flipped classroom blended learning format. While the research will need further iterations and substantive evaluation, the authors are confident that the overall approach, in which the affordances of technology are utilized through the creative applications of sound pedagogic practices and process (e.g., methods that work best and validated cognitive science principles of learning), is the most fruitful path towards highly effective and creative professional practices.

In the first part of the paper, we outline the pedagogic basis and rationale for using an evidence-based teaching approach, as well as the current framing of a flip classroom blended format. We started with a theoretical perspective that effective and efficient blended learning design should follow certain broad heuristics, for example:

1. Good learning design is *always* grounded on evidence-based practice, incorporating Core Principles of Learning
2. Information-communication technologies are used *strategically* and *creatively* to enhance specific aspects of the learning process
3. The completed blended learning design *maximizes* the affordances of a range of learning modes and mediums (Sale, 2015)

This pedagogic design model guided the development of the flip classroom lessons, integrating the online components to the face-to-face sessions, seeking to maximize the affordances of both delivery modes to optimize student learning (e.g., attainment level and intrinsic interest).

Secondly, we outline our model for teaching this module, which derived from our earlier large scale implementation of the Conceive-Design-Implement-Operate (CDIO) educational framework. The module is taught through an instructional approach that focuses on students analysing and making inferences and interpretations relating to a range of chemical process hazards at different stages of a plant lifecycle. This is to facilitate their capability for diagnosing the likely causes of such hazards, and subsequently being able to select the most appropriate strategies and tools for eliminating or mitigating the impact of these hazards. Hence, through this process, they learn how to conceive, design and implement effective preventative strategies that have a high predictive capability for maximizing plant safety.

In the final part of the paper, we present our evaluation data to date, the key pedagogic learning points, challenges faced, and potential ways to further both research and practice in this exciting new educational arena.

KEYWORDS

Evidence-based Approach, Flipped Classroom, Chemical Engineering, Safety, CDIO Standards 2 and 8

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called "courses". A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION & CONTEXT

While the use of information-communication technology (ICT) in mainstream education is far from new, evidence of widespread impact in terms of significantly enhancing the practices of teaching and, most importantly, student attainment, was not quickly forthcoming. For example, Oliver et al (2007), commenting on the lack of ICT widespread application in educational settings to create engaging and effective learning experiences noted that:

> What appears to be still missing for teachers is appropriate guidance on the effective pedagogical practice needed to support such activities. (p.64)

Robinson & Schraw (2008), in reviewing the literature on e-learning research, further supported this overall perception:

> Unfortunately, empirical research informing decisions regarding "what works" ranges from sparse at best, to non-existent at worse. This is because e-learning has focused on the delivery of information rather than the learning of that information. (p.1)

However, in the present context, there are now two particularly significant factors in the educational landscape that is rapidly changing the framing and use of ICT for teaching and learning. Firstly, there is no doubt that the available technologies in recent years, as compared to a decade or so ago, are becoming increasingly more user-friendly, varied and easily accessible. As Waldrop & Bowden (2015) point out:

> …there is no denying that the evolution of classroom technology over the past two decades has transformed the options that faculty have for using and creating multimedia course materials that can be used in and out of the classroom. (p.9)

However, of equal, if not greater, importance is the emergence of a more evidence-based approach to teaching and learning (e.g., Marzano, 2007; Petty, 2009; Mayer & Alexander, 2011; Hattie & Yates, 2014). For example, Darling-Hammond & Bransford (2005), from surveying the research findings, captured the essential framing comprehensively when they concluded:

> There are systematic and principled aspects of effective teaching, and there is a base of verifiable evidence of knowledge that supports that work in the sense that it is like engineering or medicine. (p.12)

The following sections will firstly outline the flipped blended learning format and the rationale for using an evidence-based approach. Subsequent sections summarize the specific application to a chemical engineering module and the evaluation results to date.

WHAT IS THE FLIP CLASSROOM AND HOW DOES IT WORK?

The flipped classroom is essentially a blended learning format for organizing the student learning experiences utilizing the potential benefits of blended learning. While there are many definitions of blended learning, Garisson & Vaughan (2008) capture the key elements nicely when they assert it

> …is the thoughtful fusion of face-to-face and online learning experience…optimally integrated such that the strengths and weakness of each are blended into a unique learning experience congruent with the context and intended educational purpose.
> …combines the properties and possibilities of both to go beyond the capabilities of each separately. (p.6)

As recent research is beginning to support blended learning as being both more effective than both either online or face-to-face learning (Means, Toyama, Murphy, Bakia & Jones, 2010) as well as being potentially a 'big cost saver', it's not surprising that it is now very much a key area of research focus, with the flip format being especially popular. The basic approach is that students are given an online learning experience before coming to class, often through a recorded lecture and related reading and activities (previous done through the face-to-face class lecture), which is to help them acquire the key underpinning knowledge relating to a topic area before the face-to-face session. This approach is to free up class time to apply the content knowledge thoughtfully in more real world active learning application.

At present, research relating to the effectiveness of the flip format is more descriptive rather than empirically validated (e.g., Waldrop & Bowden, 2015). Similarly, Murray, Koziniec & McGill (2015) noted that although flipped classroom has received a lot of publicity, there has been little formal evaluation of the impacts on student satisfaction or performance.

However, there are potential benefits of the flip format (Fulton, 2012; Herreid & Schiller, 2013), which include:

- students being able to learn more at their own pace
- doing "homework" in class gives teachers better insight into student difficulties
- teachers can more easily customize and update the curriculum to meet students learning needs as they arise
- classroom time can be used more effectively and creatively
- students who miss class can watch the lectures in their own time
- students are more actively involved in the learning process
- a greater positive impact on attainment and the learning experience than the traditional mode (based on self-reporting)

EVIDENCE-BASED TEACHING

Slavin (2008) noted that throughout the history of education, the adoption of instructional programs and practices has been driven more by ideology, faddism, politics, and marketing than by evidence. Certainly for many decades, it seemed, as Sallis & Hingley (1991) commented, “Education is a creature of fashion.”

However, much is changing as far as teaching is concerned and it may, as Petty (2009) argued, be ready to:

> …embark on a revolution, and like medicine, abandon both custom and practice, and fashions and fads, to become evidence-based (cover page).

Of particular significance in this area is the work of Hattie (e.g., 2009; 2012). Mansell (2008) referred to Hattie’s seminal work on the effectiveness of different teaching methods and strategies as:

> …perhaps education's equivalent to the search for the Holy Grail - or the answer to life, the universe and everything.

There is little doubt that Hattie’s work is a definitive landmark in educational research, perhaps providing a key push in the movement away from more ideological-based paradigms towards evidence-based practice in teaching. Hattie synthesized over 800 meta-analyses of the influences on learning and most significantly, he was interested not just in what factors impacted learning, but the extent of their impact - referred to as *Effect-Size*. Effect size is a way to measure the effectiveness of a particular intervention to ascertain a measure of both the *improvement* (gain) in learner achievement for a group of learners and the *variation* of learner performances expressed on a standardised scale. By taking into account both *improvement* and *variation* it provides information to which interventions are worth having.

Hattie firstly identified the typical effect sizes of schooling without specific interventions, for example, what gains in attainment are we likely to expect over a one-year academic cycle? Typically, for students moving from one year to the next, the average effect size across all students is 0.40. Hence, for Hattie, effect sizes above 0.4 are of particular interest. As a baseline an effect size of 1.0 is massive and is typically associated with:

- Advancing the learner’s achievement by one year
- Improving the rate of learning by 50%
- A two grade leap in GCSE grades

Table 1 shows examples of effect sizes in learner attainment from Hattie’s meta-analysis which featured some high impact methods on student attainment, as demonstrated by their effect sizes. However, as Hattie notes, it is important to balance effect size with the level of difficulty of interventions. For example, providing ‘advance organizers’ (summaries in advance of the teaching) have an effect size of 0.41, which is pretty average, but they only take up a few minutes at the beginning of the lesson, and potentially offer the equivalent of moving up a year in terms of a student’s achievement. He goes on to make relative comparisons of intervention use, which enables us to go beyond identifying the effect sizes for particular innovations (deliberative intervention involving strategy/method use for a group of students), and ascertain whether the effects of a particular innovation were better for students than what they would achieve if they had received alternative innovations.

Table 1. Examples of effect sizes in learner attainment from Hattie's meta-analysis

Influence	Mean Effect Size
Feedback Students getting feedback on their work from the teacher, their peers or some other sources. Note: some feedback has more effect size than others. For example, peer assessment is 0.63 and self-assessment is 0.54	0.73
Meta-cognitive strategies Students can systematically think about (plan, monitor and evaluate) their own thinking and affective processes (e.g. beliefs, emotions, dispositions) to develop effective learning to learn capability and self-regulation	0.69
Challenging goals Students having a clear frame on, and see purpose in, what they are learning, as well as experience realistic challenge in meeting goal expectations	0.56
Advanced organizers Giving students an overview (in an appropriate format and level of understanding) of what is to be learned in advance of the lesson, to help make meaningful connections between their prior knowledge and the new material to be presented	0.41

Of particular significance is the fact that it is not just the effect size of one intervention that is important, but how a number of effective methods can be strategically and creatively combined to produce powerful instructional strategies that significantly impact student attainment. As Hattie (2009) pointed out:

> …some effect sizes are 'Russian dolls' containing more than one strategy. For example, 'Feedback' requires that the student has been given a goal, and completed an activity for which the feedback is to be given; 'whole-class interactive teaching' is a strategy that includes 'advance organisers' and feedback and reviews. (p.62)

From an evidence-based perspective, it is not just the methods that work best, but also the underlying core principles of learning that facilitate the learning process (e.g., Sale, 2015; Ambrose, Bridges, DiPietro, Lovett and Norman, 2010; Willingham, 2009). For example, Sale (2015) offers the following 10 Core Principles of Learning as key guiding heuristics from which teaching professionals can plan learning experiences and teach more effectively:

1. Motivational strategies are incorporated into the design of learning experiences
2. Learning goals, objectives and proficiency expectations are clearly visible to learners
3. Learners prior knowledge is activated and connected to new learning
4. Content is organized around key concepts and principles that are fundamental to understanding the structure of a subject
5. Good thinking promotes the building of understanding
6. Instructional methods and presentation mediums engage the range of human of senses
7. Learning design takes into account the working of memory systems
8. The development of expertise requires deliberate practice
9. A psychological climate is created which is both success-orientated and fun
10. Assessment practices are integrated into the learning design to promote desired learning outcomes and provide quality feedback

The 10 Core Principles of Learning are not exhaustive or summative as new knowledge and insights will continually enhance our understanding of human learning and the implications for how we teach. However, as Willingham (2009) rightly noted:

> Principles of physics do not prescribe for a civil engineer exactly how to build a bridge, but they do let him predict how it is likely to perform if he builds it. Similarly, cognitive scientific principles do not prescribe how to teach, but they can help you predict how much your students are likely to learn. If you follow these principles, you maximize the chances that your students will flourish. (p.165)

Furthermore, just as combining high effect methods can have a powerful overall impact on learner attainment, as captured in Hattie (2009) and Petty's (2009) analogy of 'Russian Dolls', the same applies to the thoughtful and creative application of core principles of learning. As Stigler & Hiebert (1999) highlighted:

> Teaching is a *system*. It is not a loose mixture of individual features thrown together by the teacher. It works more like a machine, with the parts operating together and reinforcing one another, driving the vehicle forward. (p.75)

The following sections document the use of a flip classroom format to the teaching of a chemical engineering module, using the evidence-based approach outlined above.

REDESIGNING PEDAGOGY FOR AN EVIDENCE-BASED FLIP APPROACH

The module *Plant Safety and Loss Prevention* is a core module for the Diploma in Chemical Engineering (DCHE), taught to all Year 3 students (numbering approximately 120), in 6 classes of 18-22 students each. It is a 60-hour module with no semester examination, i.e. all assessments are based on course-work, with students working both individually and in group. To prepare for flipped classroom, the module was extensively reviewed using the 12 CDIO Standards adopted for use at module-level (Cheah and Lee, 2015). A key outcome of the module review and redesign process is the introduction of a new approach for teaching it, modelled after the lifecycle of a typical chemical process plant, as shown in Figure 1.

This insight came about from a parallel seen between the plant lifecycle and the CDIO process of conceiving, designing, implementing and operating a product or system. Also shown in Figure 1, above the 5 stages of the plant lifecycle, are the hazards associated in a typical chemical plant. Below the plant lifecycle is shown a tool box of techniques and methods and a range of risk management strategies that can be used to identify hazards that may arise at various stages of the plant lifecycle, and the approaches that can be taken to mitigate against these hazards. Figure 1 is communicated to students during the first lesson, and is used as an "advanced organizer" throughout the entire semester as this provides a key anchor point for two-way feedback in checking the development of key understanding.

A 15-week lesson master plan is then prepared to guide the detailed weekly lesson preparation. We felt this is necessary as this is the first time we embarked on designing a flipped classroom for the entire semester (i.e. 15 weeks). For each week, a set of guidance notes were also prepared, which spelt out in greater details the topics to be covered for the week, as well as the resources made available. The set of guidance notes are given to students ahead of their weekly lessons so that they can better prepare for flipped classroom. The key concepts are made explicit and reinforced via classroom activities.

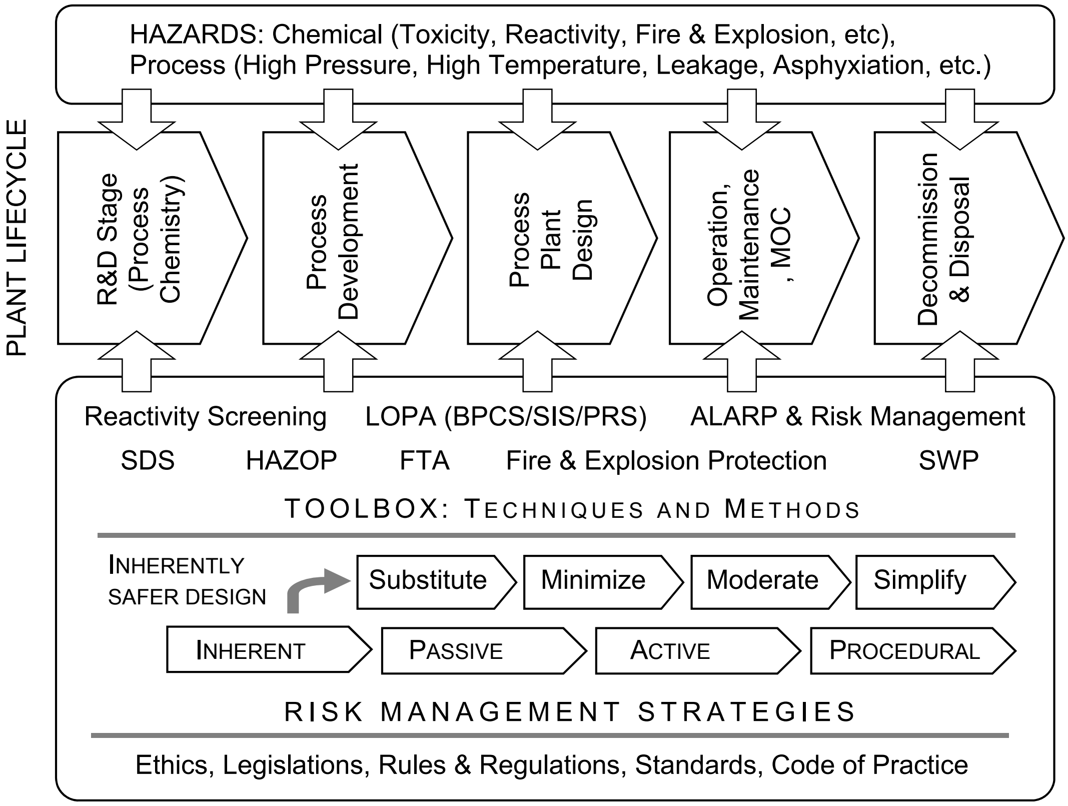

Figure 1. Lifecycle Approach to Teaching *Plant Safety and Loss Prevention*

The type of assessment evidence we seek to obtain are focused on students thinking and key understanding relating to key outcomes, such as:

1. Ability of identify from the assigned cases the correct safety issues at the proper stage of the chemical plant lifecycle
2. Ability to identify probable causes that can lead to deviation from safe operating conditions and predict likely consequences or damages
3. Ability to apply the correct preventive or mitigation strategies to prevent the occurrence or minimize the impact of any occurrence of a chemical process hazard
4. Ability to transfer lessons learnt from analysis of earlier cases to fresh cases presented at a later part of the semester

In addition, we collect data, in terms of direct feedback from students relating to our teaching effectiveness and the design of the learning tasks set. This is an important tenet of an evidence-based approach as it is necessary to ascertain how we can best teach in ways to maximize student learning opportunities.

DISCUSSION OF WORK DONE

While case study is the main teaching method employed, this is fully supported by appropriate use of ICT tools (e.g., those that enhance aspects of the leanring process and are efficient in context such as dynamic simulation), videos from various sources including U.K. IChemE (Institution of Chemical Engineers) and U.S. CSB (Chemical Safety Board) and other supporting textual and graphic resources. This utilizes different modes of presentation and methods to add variation and novelty to the learning experience.

Two key cases - namely Bhopal Gas Disaster and Piper Alpha Accident were used as "anchors" to scaffold student learning, in particular to strengthen long-term retention and transfer the application to other case scenarios, which is briefly described below.

In the flip classroom format, students first learn the key safety concepts on their own prior to coming to class, which is intented to activate their prior knowledge and go through a self-directed learning epxerience with the new material. They use the quizzes as self-assessment tools for checking understanding, and are encouraged to note areas of difficulties, which can then be addressed in the face-to-face sessions. This is usually in the form of watching PowerPoint files with narratives created using Camtasia Studio, and (where needed) videos available from YouTube or CSB web site (www.csb.gov), plus reading of journal articles or technical notes curated by the teaching team. Actual classroom contact time is 4 hours per week, in 2-hour blocks. When in class, for the first 2-hour block we firstly spend about 10-15 minutes in ascertaining students' understanding of the key concepts using a quiz comprising 3-4 multiple choice and/or true-false questions administered in real time using Socrative (www.socrative.com). This is then followed by a quick re-cap (5-10 minutes) of the important topic components and key concepts. A mini-lecture is given if results from Socrative show a significant number of students did not fully grasp the concepts covered in the self-study part of the flipped programme. This ongoing formative assessment, which fosters effective two-way feedback, is crucial to the learning process as documented by Hattie's research (2009), which reported an overall effect size of 0.73. Furthermore, the very process of engaging students more in two-way feedback activty seems to enhance the building of rapport with them, as students may be perceiving this as showing greater interest in their learning. For the rest of the class time, we then use the "anchor" cases to demonstrate how safety principles were violated in these accidents. We place particular emphasis on how these accidents could have been avoided had systematic analysis been given at different stages of the plant lifecycle; and appropriate safety protective measures (both preventive and mitigative) measures were put in place. Then, during the next 2-hour block, students are now required to apply the understanding learnt from the Bhopal or Piper Alpha case to display transfer of leanring to different scenarios. Here we use another "anchor" case study, based on the EnVision Dynamic Simulation System's Amine Treating Unit (ATU), which is supplemented with other case studies as appropriate to further strengthen the transfer outcome.

All the learning tasks for engaging students in the classroom are decided by what strategy and method combination is most likely to work, and applied thoughtfully in terms of core principles of learning. Key strategies used include: activation of prior knowledge, direct instruction, peer tutoring, feedback, advanced organizer, etc. Some of our approaches took on the characteristics of "Russian Dolls", in terms of the analogy mentioned earlier. In addition, we also based the design of our learning tasks based on recent research that highlighted the effectiveness of repeated testing in promoting the transfer of learning to new contexts (Rohrer, Taylor and Sholar, 2010; Carpenter, 2012), by repeatedly revisiting earlier concepts in later weeks of the lessons.

Classroom discussions utilize Google Doc, whereby a class of 18-22 students is divided into 4-5 groups of 4-5 students each. Students discuss and present a group answer to the questions posed by typing in real time into the response box created in Google Doc. In some situations, students are asked questions that have more than one answer, so each group is required to provide a different answer. In other situations, different questions are asked to each group, so that they need to collaboratively come up with part of the answer. We also encouraged academically stronger students to help their weaker counterparts, to co-create the response together, hence fostering a sense of cameraderie. Indeed, as noted by Boettcher (2006), the key benefit of learner-generated content lies in the processes of creation, knowledge construction, and sharing as opposed to the end product itself.

Important concepts such as inherently safer design, layer of protection analysis, etc. are repeatedly revisited at later topics in subsequent weeks. Hence, review was systematically employed to ensure consolidation of key knowledge in long-term memory. Appendix 1 provide 2 examples of learning tasks prepared for Week 13 in which we covered chemical hazards. For this week, we used a new case study involving an incident at Formosa Plastics Corp available from YouTube, and require that students revisit how the loss prevention strategies can be used at different stages of the plant lifecycle. In a similar vein, students are required to apply the concepts of inherently safer design learnt in Week 1 to a new case of “Fatal Exposure – Tragedy at Du Pont”.

Conceptual understanding is particularly important for long term retention and transfer. To facilitate this, evidence obtained from Socrative is used to ascertain students understanding of a given concept, as explained earlier. Difficult concepts are reinforced in subsequent activities. Appendix 2 showed two examples of how we make use of Socrative in real time to better understand students' grasp of the concepts presented. For the first example (top), the majority of students selected the wrong answer 'A', which means that they still had difficulty applying the concept of SIS (safety instrumented system) to certain aspects of chemical plant operation. The second example (bottom) showed a typical Excel output from Socrative, which summarized individual student's performance during a particular quiz session.

Evaluation of student’s ability to apply the concepts is done in-class using students' work in Google Docs. The lecturer provides feedback, also in Google Doc, to students on their entries during class time where possible, for example as shown in Appendix 3. In this case, from the responses given, the lecturer can immediately ascertain that students had difficulty with the application of inherently safer design in terms of process chemistry, when he noted that none of the groups provide an entry under this category.

EVALUATION

At the end of the semester, a survey is conducted to ascertain the student’s learning experience using the flipped classroom approach. A total of 40 students responded to the survey, representing approximately 33% of the total Year 3 cohort. Figures 2-7 represent the survey findings.

Overall, majority of students reported that they are able to understand the information (mostly concepts and strategies related chemical plant safety, and factual information such as definitions of technical terms, safety procedures, properties of chemical substances, standards and codes of conduct, etc.) in the pre-recorded videos to be useful (Figure 2). All the students are new to flipped classroom, and thus it is not entirely surprising that many of they took significantly longer time to get used to this method of learning. As can be seen in Figure 7, up to 20% of students reportedly required over 8 weeks (i.e. more than half a semester) to get accustomed to flipped classroom. A large majority of students also either "Agree" (52.5%) or "Strongly Agree" (7.5%) that they found the lifecycle model of chemical process plant (as depicted in Figure 1) served as a useful "sign post" to help them stay on course in the lessons

(Figure 6). Students also agreed that the use of case studies is useful in helping them understand the module better (Figure 3), and that they felt more engaged in the classroom via activities such as answering questions in Socrative or collaborate with one another in Google Doc (Figure 4).

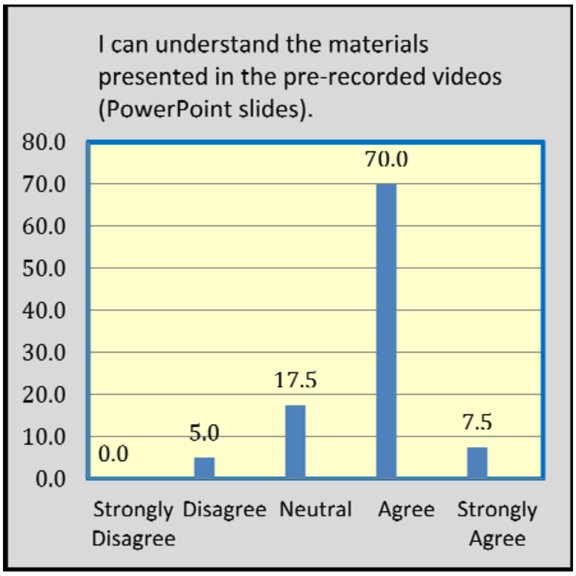

Figure 2. Understanding of pre-recorded lectures

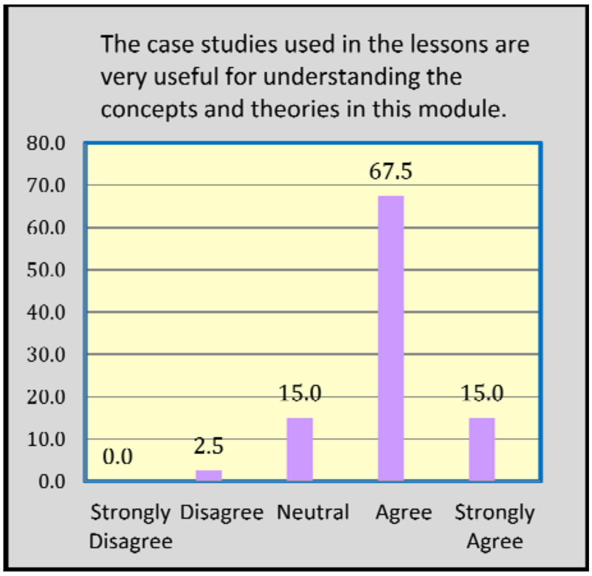

Figure 3. Usefulness of case studies

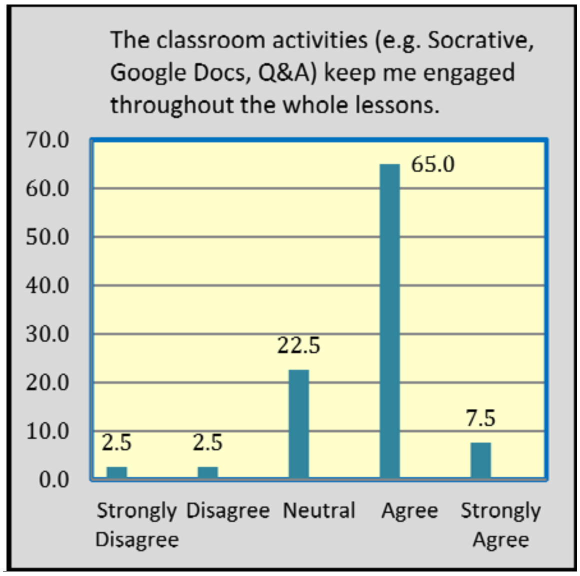

Figure 4. Classroom engagement

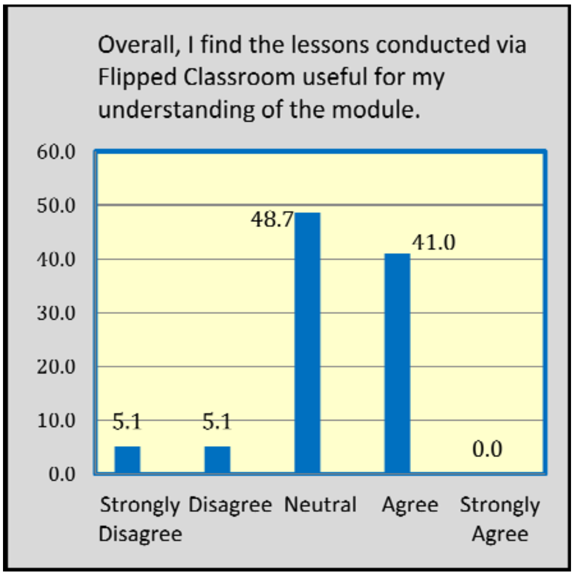

Figure 5. Overall experience on flipped classroom

Despite these positive outcomes, as shown in Figure 5, many students are still ambivalent about flipped classroom: whereby only 41.0% agreed that lessons conducted via flipped classroom are useful to their learning. Almost half (48.7%) of the students would rather chose a "Neutral" position on this question.

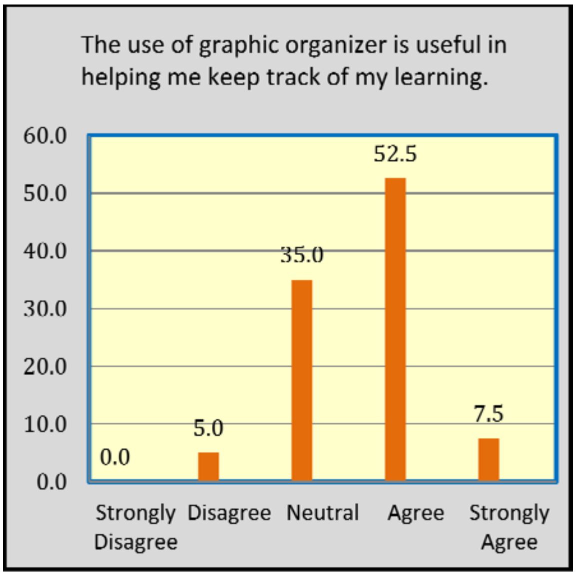

Figure 6. Usefulness of graphic organizer

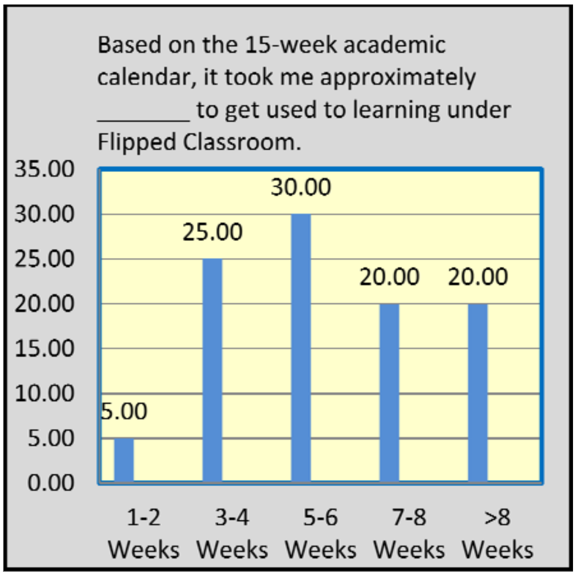

Figure 7. Adjustment period for flipped classroom

One limitation of the present research is that the evaluation lacked a control group for comparison. Having a randomised control group has been touted as the "gold standard" for evidence-based practice (Buckley, 2009). However, in our present Singapore context, this is not ethically feasible as student sensitivities, especially being perceived as being “left out” from potentially beneficial teaching and learning approaches, and allegation of being placed in “disadvantaged positions” affecting their Grade Point Average is always a serious concern. This is especially true in today’s world, whereby students can take issues by voicing their dissatisfaction via social media.

Comparison of students’ attainment between this cohort and a previous cohort, which was not subjected to flipped classroom is also not feasible, as the assessment schemes used for the two cohorts are not the same. In fact, if we were to compare the module average mark for the two cohorts, we found that the previous cohort of students appeared to have fared 'better' than current cohort of students, as shown in Table 2.

Table 2. Comparison of Performance of Two Cohorts of Students

Cohort of Students	No. of Students	Module Average Mark
Previous (no flipped classroom)	62 (Sem 1) + 52 (Sem 2)	78.10
Current (with flipped classroom)	124 (Sem 1 only)	75.59

Such a result should not be negatively interpreted re use of a flipped blended learning format. As noted earlier, the assessment schemes for the two cohorts are not the same. For the current cohort of students we set more challenging questions, focusing on transfer of knowledge, with more in-depth applications of key concepts rather than largely assessing factual knowledge with limited real-world application. A further comparison of the two cohorts is shown in Figure 8, in terms of grades attained (where AD = Distinction, P/F = Pass Fail). No doubt the number of students who scored ‘A’ has dropped somewhat, we felt this is acceptable given the rationale given earlier. This is more or less ‘compensated’ by the increased in number of students getting

'B' grades. We also have 10 students more in the present cohort. We ignore the 3 students who were given a Pass/Fail grade as this is the result of them not fulfilling a new attendance requirement introduced in SP, rather than poor performance per se. At the time of writing this paper, the module team has already carried out certain pedagogic interventions to improve students' learning under the flipped classroom approach. These include enhanced feedback opportunities, especially the use of peer marking.

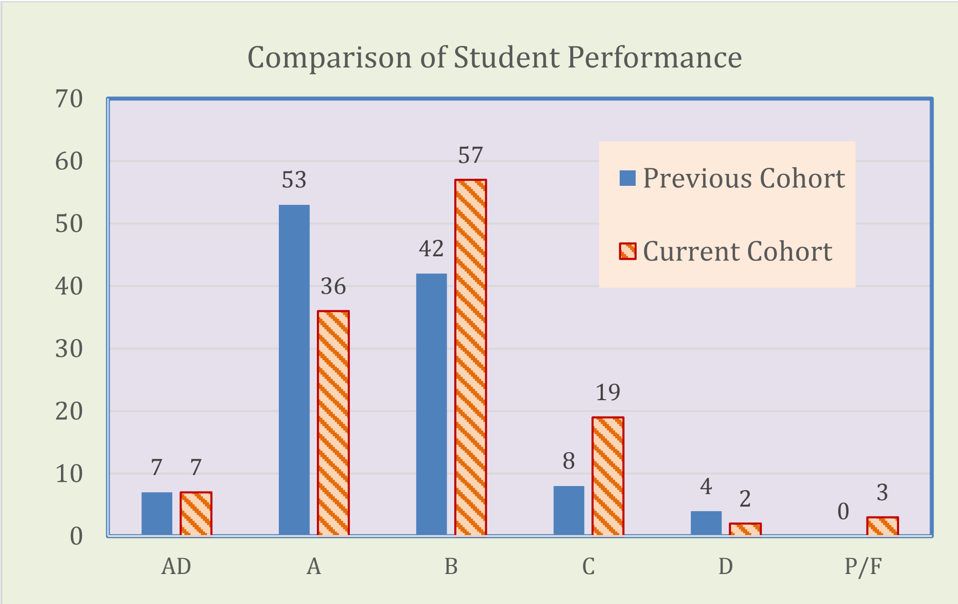

Figure 8. Comparison of Grades between two Cohorts

A second limitation of the research concerns the scope and depth of the evaluation. While focused on certain key areas relating to the impact of the flip classroom and some specific pedagogic practices, a more comprehensive and deeper evaluation approach is needed in future. This has been identified as a main focal area to address for subsequent research.

KEY CHALLENGES FACED

Invariably, any significant change in teaching practice throws up a wide range of challenges. For example, as this current cohort of students are new to the flipped classroom approach, a significant number of them had a difficult time adjusting to this way of learning. Although there was some initial resistance, the students gradually adjusted to the format, especially when they realized that the lecturers are serious in using this new approach. Therefore, it is important for the instructor to establish expectations early in class. Overall, we feel that the decision to implement a flipped classroom for the entire semester, as compared to a more partial approach, was vindicated. The flipped classroom, like any new learning format, takes time for students to adjust to, and so short-time use may not be realising the full benefit of a flipped classroom (Mason, Shuman and Cook, 2013).

Furthermore, as the entire original module materials had been shifted to out-of-class activities, the flipped approach afforded the team opportunities to cover more material than that in a traditional classroom. However, this also meant that we had quite a bit of developmental work to do, starting more or less from scratch. We estimated that approximately 80% of the content for the 60-hour module is new. With the module slated for its first appearance on April 2015, the team had started the preparation work back in September 2014. Even with this lead time (or so we thought), when the module was actually rolled out the team had to cope with minor modifications to some of the learning tasks at various points throughout the entire semester.

A key learning point for us was the realization in practice that a successful flipped classroom must provide students with adequate structure (Mason, Shuman and Cook, 2013). One challenge we faced was that some students did not come to the class prepared. This may be because no marks were allocated for the pre-class test mentioned earlier. However, we resist the temptation to reward students with marks for this purpose, and instead reinforce in them that they need to take responsibility for their own learning. We had to make a conscious decision not to cover the lectures in any great details in class, and eventually all students will "get the message". For difficult concepts such as HAZOP and Fault Free Analysis, which is rather procedural in nature, we take the students through worked examples in class, although they are still required to understand the methods on their own study time.

Another important issue that challenged us concerned the varied student prior experience in chemical plant operation. Not surprisingly, most of our students had limited knowledge of real-world operation of a chemical plant. To ensure that they had an acceptable level of understanding, we created a self-learning package based on the Amine Treating Unit from EnVision. This is the same dynamic simulation model that was mentioned earlier as the key mechanism that we use to ascertain our students' ability to transfer the learning gained from the Bhopal and Piper Alpha anchor cases. The package consists of detailed description of the amine treating process, piping and instrumentation diagrams, control and safety systems, etc, plus a suite of self-paced simulation exercises so that students can familiarise themselves with the amine plant operation. Through this, we hoped to impart the requisite experience (albeit a virtual one) to the students. On hindsight, we should have surveyed the students on their learning experience practicing on a virtual model, to ascertain the usefulness of the material that we prepared.

CONCLUSIONS

The challenge of designing and facilitating the student learning experience from an evidence-based teaching approach using the flipped classroom format was an exciting one. We feel the results are encouraging, particularly as this is a new innovation, and the real benefits may not be manifested until sufficient expertise is honed in the design and facilitating process. Hence, this will continue as an ongoing professional development activity. As Dziuban, Hartman & Moskal (2004) point out:

> Maximizing success in a blended learning initiative requires a planned and well supported approach that includes a theory-based instructional model, high quality faculty development, course development assistance, [and] learner support. (p.3)

Certainly we feel that an evidence-based approach is the most logical theory-based instructional model to underpin our teaching using the flip classroom format. Our future goal is to improve the capability of maximizing the blend of high effect size teaching methods and the affordances of the flip format to create highly effective, efficient and creative learning experiences for the students we teach. This we feel is a real merging of the science and art of teaching.

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BIOGRAPHICAL INFORMATION

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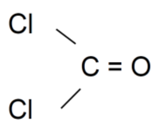
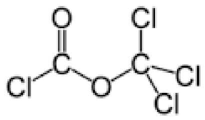
Appendix 1 Selected Examples for Week 13

Activity 3: **LEARNING FROM ACCIDENT - Inherently Safer Design Revisited**

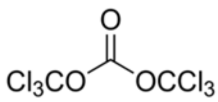
Despite its toxicity, phosgene is still widely used in industry as a chemical intermediate for isocyanate-based insecticides, polymers, and pharmaceuticals. It is manufactured through the reaction of carbon monoxide and chlorine. It is reacted with primary amines to form isocyanates (R-N=C=O). Isocyanates are a family of highly reactive, low molecular weight chemicals. They are widely used in the manufacture of flexible and rigid foams, fibers, coatings such as paints and varnishes, and elastomers, and are increasingly used in the automobile industry, autobody repair, and building insulation materials. Alternatives to phosgene such as diphosgene and triphosgene had been proposed:



(Phosgene)



(Diphosgene)



(Triphosgene)

Explain how the 4 Chemical Process Safety Strategies of *Inherent, Passive, Active, Procedural*, can be used to improve safety in the company's phosgene unit.

Share your answers in Google Doc using the link given.

Activity 6: **LEARNING FROM ACCIDENT - Application of Loss Prevention Principles at Different Stages of Plant Lifecycle**

Instruction to Students

Watch the CSB Video “Fire and Explosions at Formosa Plastics Corp” (8:23 mins) available at the CSB web site or YouTube at https://www.youtube.com/watch?v=gDTqrRpa_ac
Obtain the sample MDSD for propylene from Praxair available at the module Blackboard site.
Identify issues highlighted in this video and organize them under the following categories related to principles of loss prevention learnt earlier:

- Process Description – present the relevant information obtained from the given SDS
- Plant Design
- Plant Layout
- Plant Operation

Using suitable search engine, find out more about “fireproofing” mentioned in the video.

Apply Loss Prevention Principles in...	DCHE/3A/03	DCHE/3A/04
Process Description	A	A
Plant Design	B	B
Plant Layout	C	C
Plant Operation	D	D
Finding out about "Fireproofing"	E	Any Group

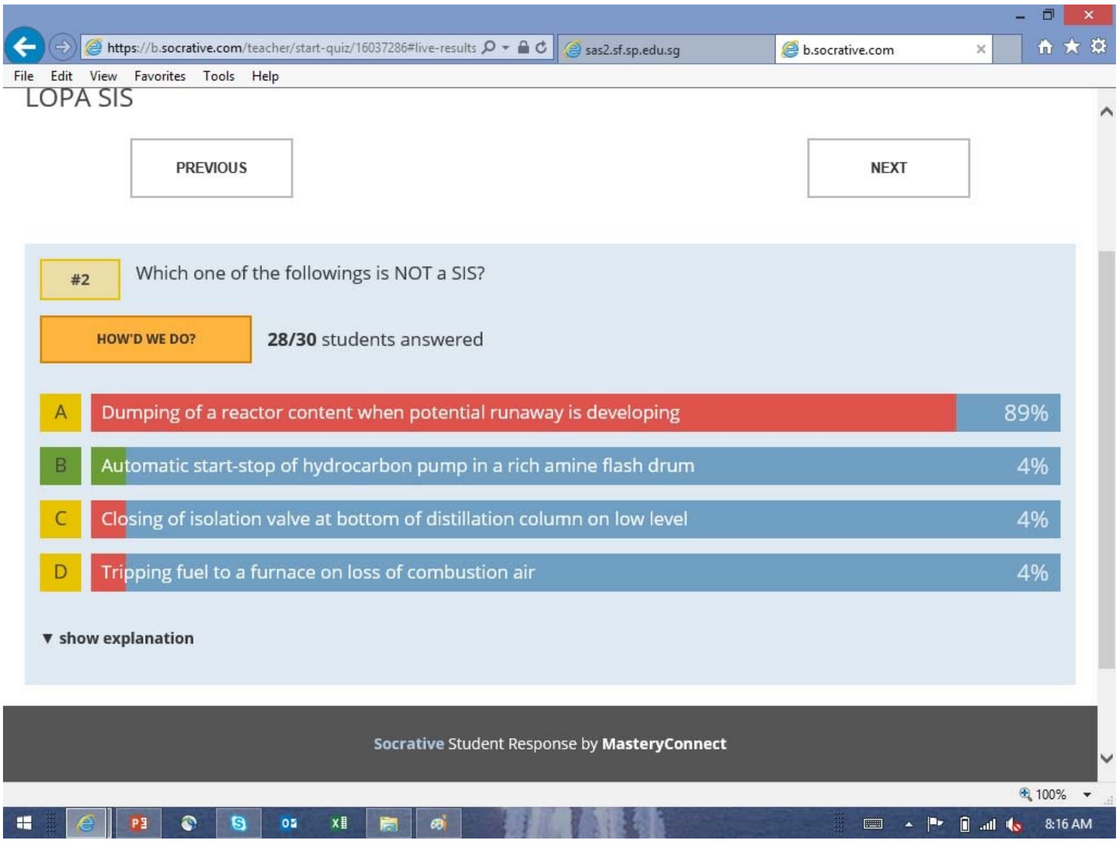
Submit your entries using the Web 2.0 Tools Padlet available from the link below:

DCHE/3A/03: http://padlet.com/smcheah/CP5033HBL-T-DCHE03

DCHE/3A/04: http://padlet.com/smcheah/CP5033HBL-T-DCHE04

Please refer to earlier instructions on using Padlet.

Appendix 2   Sample outcomes from "Concept Checkpoint" session using Socrative



This example shows that majority of students are quite clear about answers C and D, which are correct examples of Safety Instrumented System (SIS), but not so certain between answers A and B.

Strategies for Loss Prevention
Tuesday, April 28 2015 08:21 AM
Room: CP5033

Student Names	Total Score (0 - 100)	Number of correct answers	The four chemical process safety strategies in order of robustness and reliability are:	It is stated that "Hazards are intrinsic to a material, or its condition of use" .Which one of the following is WRONG in trying to eliminate/reduce the hazards?	Which one of the followings is NOT an "active" chemical process safety strategy?	Dilution and refrigeration are examples of the inherently safer design of ____________.
1	80	4	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
2	80	4	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
3	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Minimize
4	40	2	Inherent, Passive, Active, Procedural	Change the person using the material	Emergency vent valve triggered by high pressure in vessel	Minimize
5	40	2	Inherent, Passive, Active, Procedural	Change to a different, non-hazardous material	Containment dike around a hazardous liquid storage tank	Minimize
6	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Minimize
7	20	1	Active, Inherent, Procedural, Passive	Adopt a different way of using the material	Containment dike around a hazardous liquid storage tank	Minimize
8	80	4	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
9	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Minimize
10	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Simplify
11	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	
12	40	2	Inherent, Passive, Active, Procedural	Eliminate the use of the material	Containment dike around a hazardous liquid storage tank	Minimize
13	60	3		Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
14	80	4	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
15	80	4	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Moderate
16	60	3	Inherent, Passive, Active, Procedural	Adopt a different way of using the material	Containment dike around a hazardous liquid storage tank	Moderate
17	40	2		Change the person using the material	Containment dike around a hazardous liquid storage tank	Minimize
18	60	3	Inherent, Passive, Active, Procedural	Change the person using the material	Containment dike around a hazardous liquid storage tank	Minimize
19	40	2	Inherent, Passive, Active, Procedural	Change the person using the material	High level alarm to trip a reactor feed	Minimize

This is the original raw data (boxes coloured by author) from Socrative's export into Excel format. This is a summary of a "concept checkpoint" session comprising 4 multiple choice questions. Such data can easily be converted to graphical display e.g. pie chart for better clarity.

Appendix 3 Sample Entry in Google Doc for Student In-class Work on Application of Strategies of Inherently Safer Design to Case of Bhopal Gas Disaster
(Text in Comics San MS are author's feedback to students)

Area of Application of Loss Prevention Principles	Case of Bhopal (explain why it is not desirable)	How application of Inherently Safer Design can reduce the hazard(s).
Plant operation	Refrigeration system decommissioned for a long time. Safety interlocks bypassed. Vent scrubber decommissioned. SOP not followed, blind not inserted. Flare tower under maintenance since long time ago, not enough manpower. Control instruments such as T and P gauges not working properly	(Design) Moderate - The refrigeration system should never be decommissioned to ensure safer storage of MIC. YES! That is correct. Minimise - Storage of MIC should be done in smaller tanks. 10 small tanks are safer than 3 large tanks. Better still and to adhere strictly to the principles of ISD: have 3 smaller tanks. Otherwise the tendency is to fill all 10 small tanks! Substitute - Since water reacts with MIC in a exothermic reaction, alternative material such as nitrogen or plant air can be used to purge or wash the pipes during maintenance Good thinking. You got that right!
Plant layout and design	There was supposed to be four vent gas scrubbers for stand-by. Since in Bhopal there was only one vent gas scrubber. There was no standby vent for maintenance. The capacity of the flare is incapable in managing the volume of waste gas produced.	Vent, flares etc are not part of inherently safer design. They are 'add-ons' installed to mitigate any consequence of MIC leak. They fall under the active (as opposed to passive) protection strategies. Since this group identify the area of loss prevention as "Plant layout and design", for the layout part you could consider the location of the plant - it is close to slum areas where a large population existed. One can SUBSTITUTE this location with one which is safer, and not have the wind blowing MIC in its direction.
Plant design	Using carbon steel instead of stainless steel for plant design. after a long time, rust will form which is the catalyst that triggers the reaction between MIC and water.	Substitute - Use stainless steel instead to reduce the chance of formation of rust hence reducing the amount of catalyst produced, thus leading to a slower reaction between MIC and water even when there is water flow into tanks. GOOD - you got this right!

OVERALL COMMENTS:

Most of the answers above centred about Plant Design or Operations. Remember that more can be achieved by considering Process Development at the earliest opportunity, at the R&D stage. One can consider not using this reaction chemistry between phosgene (itself a toxic substance) and MMA altogether, and use something much less hazardous. This will achieve the aim of SUBSTITUTE of ISD. If really the MIC route must be used, then the next best thing to do, is to MINIMISE the quantity of MIC stored on-site.